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THE UNIVERSITY OF ALBERTA

DEVELOPMENT OF THE MINERAL RESOURCES OF NORTHERN CANADA

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF ARTS

DEPARTMENT OF POLITICAL ECONOMY

by

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EDMONTON, ALBERTA

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Abbreviations

The following abbreviations have been used to indicate the source of data:

A.B.M.S.	American Bureau of Metal Statistics, Yearbook 1958
D.B.S.	Dominion Bureau of Statistics, Canada Year Book 1959
U.N.	United Nations, Statistical Yearbook

Chapter I

Canada's mineral resources are in no small way responsible for the enviable position the country occupies in the world today. In recent years Canada has become a very important producer and exporter of a long list of valuable mineral products. In addition, the country is rapidly assuming a position of prominence among the "middle powers" and ranks high in terms of Gross National Product on an aggregate basis and second only to the United States on a per capita basis.

However, in other respects Canada is still a country with an economy which, by modern standards, is far from being fully developed. The immaturity of the economy is apparent in at least two aspects. First, Canada exports raw materials in very large quantities and at the same time depends upon sources abroad for a substantial proportion of her requirements of manufactured goods, many items of which are fabricated from the materials that Canada exports. Secondly, there are large areas of the country that are not served by transportation or other facilities and which have rich undeveloped natural resources. There are other sectors of the economy that have yet to attain the stature one could expect in full development, but it is these two aspects of economic immaturity that are of concern here. In particular, the problems surrounding the exploitation of the undeveloped mineral resources are to be considered.

In brief, the objective of this thesis is an examination

of the market factors that would affect the timing of the development of the mineral resources in the now relatively inaccessible regions of Canada.

To define a little more closely the scope, the following limitations have been placed on this study. The inaccessible regions are taken to include the Yukon and Northwest Territories, the Arctic Islands and the Ungava Peninsula of Quebec. Furthermore, although entirely relevant to a study such as this, fuel minerals will be excluded due to the complexity of the topic. Most of the non-metallic minerals will also be excluded from consideration because exploitation, except for local consumption, must inevitably be long delayed due to their low unit value. Principal attention will thus be directed to the metallic minerals. No attempt will be made to anticipate technical innovations that might assist in the development of the mineral resources of these remote areas. Closest attention will be given to the factors that affect the supply and demand situation for metallic mineral products.

It is not proposed to dwell to any length on the benefits that will accrue to Canada by the profitable exploitation of the country's natural resources for they have been outlined in considerable detail elsewhere[1,2,3]. The direct benefits arising from a mining operation are readily evident. Employment is provided by the mine operation itself and the supplies needed add further impetus to the growth of any economy. The indirect benefits are also of great significance, particularly in underdeveloped areas, and take the form of power, transportation, communication and other

facilities required by an industrial community. These indirect benefits, together with the social welfare facilities required by such enterprises and partly financed through the taxes collected from the mine operators, all help in the development of an area. A further factor of no less significance is that in a country with an economy that is not fully matured, the mineral products are often exported, so providing foreign currency. Sources of foreign currency from the export of raw materials can be a major factor in the growth of an underdeveloped country, since this money is needed for the purchase of manufacturing equipment so that raw material and labour resources can be utilized most effectively. Only a well-developed economy can produce, in addition to the required consumer goods, its own capital goods and thus not require a supply of currencies from the highly industrialised nations. As we shall see, Canada still imports significant quantities of machinery and capital goods of all description.* A source of foreign currency can be used equally for outright purchases abroad and for securing loans. In fact, if wisely managed, mining can and does provide the foundations for later industrialisation when required to do so.

In order that the problems of the development of the inaccessible regions can be seen in perspective, the state of the Canadian economy will be reviewed briefly and the present rôle of the minerals industries will be examined in some detail. These topics will be covered in this first chapter. The second chapter will deal in detail with the anticipated demand for mineral products over the next quarter century. This chapter will draw heavily upon

*It is interesting to note that the proportion of capital goods that are imported has increased in recent years.

a number of recent surveys that have investigated the future world requirements of raw materials. When the future demand for raw materials is considered, the effect of substitutes will also be taken into account so far as is possible without indulging in technological speculation. The third chapter will be devoted to an examination of the world supply of metallic mineral products. The final chapter will be an attempt to draw conclusions from the material in the foregoing chapters and so to predict to what extent the development of the mineral resources in the inaccessible regions is likely to progress in the next twenty-five years.

This study has been undertaken because it is felt that, if the exploitation of mineral reserves in Northern Canada is to be motivated by profit considerations, markets for these mineral products must exist, and thus an investigation of the future supply and demand situation will be of value. Moreover, even if substantial government assistance were to be provided at some time during the period under consideration, some assessment of the markets for these materials is still needed. The importance of an appropriate supply and demand position cannot be over-emphasized, for without favourable conditions these resources become, for the time-being, worthless.

An appraisal of the Canadian economy shows that in many respects it is not fully developed, particularly in terms of its industrial potential. This supposition is shared alike by Canadians and by the peoples of the United States and Europe. The reasons for

these views are not hard to find. The presence of the highly developed economy of the United States to the south and of the large expanse of unpopulated and unexploited territory to the north are two obvious factors.

However, although Canada is in some senses an underdeveloped country, the nature of economic immaturity differs from that of other underdeveloped countries. Canada has no large indigenous population scarcely able to provide itself with the necessities of life, as so often is the case before a community attains full economic maturity. In other ways also, Canadian economic immaturity is different from that of the nations of South-East Asia for instance. By the analysis suggested by Higgins, Canada in many ways resembles the United States, Australia and the Union of South Africa, although, as compared with the former of these, she is short of capital[4]. Canada is very well endowed with land and raw material resources, somewhat short of capital and very short of labour. However, although the labour force is small in numbers, it is of very high quality and Canada regularly recruits immigrants from Europe to populate the country. The desire to develop the unexploited natural resources does not spring from a need to alleviate conditions of dire poverty, but, as much as anything to stimulate industrial activity in the country as a whole, and to raise even further the already high level of prosperity in the country.

Before presenting an outline of the rôle of the mineral industries in the economy, some observations on recent developments in the economy as a whole will be of benefit. During this century, and the last twenty years in particular, the Canadian economy has

grown very rapidly. The country now enjoys a high standard of living which is in many respects second only to that of the United States. For the nineteen years from 1939 to 1958, the Gross National Product in constant dollars has risen almost 5% each year. This growth in the economy was stimulated in part at least by a population growth of a total of 53.5% and was supported and strengthened by an annual gross investment which in recent years has amounted to as much as 25% of the Gross National Product while net investment has ranged between 10 and 12% in these years[5,6].

Much of the growth of the economy has come since the war, and has been largely in the initial stages of manufacturing and in the service sector. This growth is illustrated by the figures presented in the accompanying Table I-1. It is quite evident that the manufacturing industries, as measured by the value added by manufacturing, are the largest single sector in the economy when the classification of the Dominion Bureau of Statistics is adopted.

TABLE I-1 The Canadian Economy, 1939 and 1955[7].

Sector	Output $'000,000		Value added $'000,000		No. employed '000	
	1939	1955	1939	1955	1939	1955
Total (current $)	5,710	27,070	-	-	4,196☆	5,180☆☆
Agriculture	1,225	3,290	-	-	1,084☆	827☆☆
Mineral	207	1,156	-	-	46	107
Forest	160	830	-	-	na	149
Manufacturing:	3,475	19,514	1,531	8,753	658	1,298
Wood, pulp and paper	580	3,129	304	1,499	145	223
Food	784	3,614	527	1,258	100	181
Non-ferrous smelting and refining	263	1,212	80	444	12	29
Primary iron and steel	76	526	40	292	14	33

☆ 1941 Census figures ☆☆ 1951 Census figures

Although the manufacturing industries predominate, they are actually an integral part of an economy which is still much concerned with the production and primary processing of raw materials. Thus the proportion of the labour in the country that is engaged in primary industries is somewhat more than in the industrialised countries such as West Germany and the United Kingdom. These figures are contained in Appendix I. In 1955 the value added by the manufacturing of agricultural products, that is to say the food industries, amounted to over 1 billion dollars. Similarly the industries processing the products of the forests and the mines added a value of more than 2 billion dollars to these commodities.

A further change in the economy in recent years has been the relative decline in importance of agriculture and the growth of the mineral and forestry products industries. Thus since 1946 the contribution of the primary minerals industry has grown from 2.9% of the Gross National Product to 4.5% in 1956, while the value of primary agricultural products fell from 14.6% to 8.8%.

Taken together, it is believed that these figures suggest a burgeoning industrialisation of the Canadian economy. Let us now attempt to assess the stature of the Canadian mineral industry and its rôle as a sector of the whole economy. By any standard the Canadian mineral industry has already reached a high level of development. Table I-2 shows the Canadian output of a number of metals in 1957 and the rank of this production rate among world producers[8]. Canada was the largest producer of asbestos and nickel, and ranked among the top five in aluminum, gold, platinum metals,

uranium oxide, zinc, cadmium, cobalt, magnesium, molybdenum, silver, titanium ore, copper and lead.

TABLE I-2 Canada's Position as a Producer of Mineral Products, 1957. (D.B.S.)

Product	Output tons	Value $'000	Rank by Volume*
Asbestos	1,061,000	104,489	1 (-)
Nickel	188,000	258,977	1 (1)
Aluminum	577,000	363,623	2 (2)
Gold (troy ozs.)	4,436,000	148,757	2 (3)
Platinum metals (ozs.)	409,000	25,731	2 (-)
Uranium oxide (lbs.)	12,875,000	136,304	2 (-)
Zinc	410,000	100,042	2 (2)
Cadmium	1,170	4,026	3 (-)
Cobalt	1,868	7,784	3 (-)
Magnesium	8,000	5,255	3 (4)
Molybdenum	437	1,167	3 (-)
Silver (troy ozs.)	28,362,000	25,183	3 (3)
Titanium ore	269,000	97	3 (-)
Copper	346,000	209,899	4 (5)
Lead	181,000	50,670	4 (5)

*The figures in brackets include the U.S.S.R. among world producers where data are available.

It is thus evident that Canada must be included among the large mineral producers of the world and it is appropriate to enquire to what extent the industrialisation and the development of the mineral resources are related. The first aspect of the matter to be examined is a consideration of the proportion of mineral output used by Canadian industry and that exported. An assessment of the situation can be gained from Table I-3 which sets out the total output, Canadian consumption, Canadian production as a proportion of the world output and the apparent exports. It appears that for many metals and mineral products, notably nickel, iron ore, zinc, copper, lead and aluminum, a very substantial proportion is used abroad.

TABLE I-3 Canadian Output, Consumption and Export of Selected Mineral Products[9].

Mineral	Year	Canadian Output tons'000	% of world	Canadian Consumption tons	Apparent Exports tons'000	% of Output
Nickel	1939	115	--	1,000	114.	99.0
	49	130	79.9	2,500	127.5	98.0
	56	175	63.0	6,500	168.5	96.2
	57	190	60.0	5,200	184.4	97.1
Iron Ore	1939	500	.2	2,000,000	nil	nil
	49	4,000	1.6	3,000,000	1,000.	25.0
	56	22,500	5.1	7,000,000	15,500.	68.9
	57	22,000	4.8	6,000,000	16,000.	72.6
Copper	1939	305	--	60,000	245.	80.4
	49	250	10.5	100,000	150.	60.0
	56	355	9.5	145,000	210.	59.1
	57	359	9.3	118,200	241.	67.1
	58	347	9.2	123,000	224.	64.5
Zinc	1939	197	--	23,000	174.	88.5
	49	288	14.1	46,000	242.	83.6
	56	423	13.3	65,000	358.	84.5
	57	414	13.0	70,000	344.	83.0
	58	424	13.8			
Lead	1939	194	--	38,000	156.	80.5
	46	160	9.7	51,000	109.	68.0
	56	189	8.2	68,000	122.	64.5
	57	181	7.5	55,000	116.	64.0
Aluminum	1939	83	--	11,000	72.	86.6
	49	397	27.3	59,000	338.	85.1
	56	597	16.9	90,500	506.5	84.9
	57	555	15.1	82,200	473,3	85.1

It is also apparent that, although the Canadian output of all of the metals listed except lead has increased significantly through the last two decades, this country's share of the world's production has in many cases fallen. Furthermore, except for iron ore, a larger proportion of the output is used in Canada than was before the War. These changes in the supply and consumption patterns are due to the growth of industry in Canada and to the development of the mineral resources of Africa and South America. It is also of

note that the consumption of metals in this country has, proportionately, grown much more rapidly than the population.

A matter that is of interest in any discussion of the degree of development of an economy is the form which its exports take. Good arguments can be put forward to support the view that an economy will not have attained full stature until all its exports are in the form of highly manufactured goods, for only then will the exporting country draw the greatest benefit from its natural resources.[*] These arguments neglect the benefits of trade and of international specialisation, but often a democratic government finds it difficult to resist the pressure imposed by a group seeking an economic benefit if no obvious harm is done to others. Furthermore, opposed to these arguments are the facts that many countries will always lack some items of the complete range of materials required by modern technology and that much more is involved in the manufacturing process beyond a supply of raw materials. It is, thus, quite conceivable that a country can be fully industrialised, in that it manufactures all it can, economically, and yet it still exports raw materials in an incompletely fabricated state. It is probable that the most highly manufactured form in which metals surplus to the manufacturing requirements of exporting country can enter world trade is as a semi-fabricated shape such as rods, sheets, bars, tubes, channels, strip and structurals. Table I-4 shows that though much of Canada's metal exports are in the form of refined metals, actually only a small proportion has been to any extent manufactured[10].

[*] Hon. Alvin Hamilton, address to the Annual Meeting of the C.I.M. April 14, 1959, Montreal.

TABLE I-4 Form of Canada's Metal Exports (D.B.S. Trade of Canada).

Metal	Year	Concentrate or Ore %	Refined Metal %	Semi-fabricated and finished %	Total $'000,000
Iron and Steel	1956	31.4	14.3	54.3	458.8
	57	29.4	15.5	54.9	518.8
Nickel	1956	38.6	61.4	nil	222.9
	57	39.9	60.1	nil	248.3
	58	43.5	56.5	nil	212.6
Copper	1956	20.6	69.0	10.4	205.5
	57	18.0	73.7	8.3	169.2
	58	12.6	79.0	8.6	141.8
Lead	1956	38.9	61.1	nil	35.0
	57	36.3	63.7	nil	29.5
	58	41.1	53.9	nil	26.1
Zinc	1956	36.4	63.4	.2	74.2
	57	32.9	66.8	.3	65.1
	58	39.5	60.3	.2	55.6
Aluminum	1956	nil	97.4	2.6	236.2
	57	nil	95.8	4.2	230.5
	58	nil	94.9	5.1	223.6

The only substantial export of manufactured goods that contain metals are those of an iron or a steel content and here the situation is rather different, as will be seen later. There are several factors which limit the export of metals in a semi-fabricated form. These include the degree of industrialisation of the exporting country, ease of communication between exporter and consumer and the tariff structure established by the importing country. So far as the first of these requirements is concerned Canada is well placed. There are at present four brass mills which together could handle the entire copper output with very little additional equipment. Canadian industrial development has also progressed far enough that there are adequate facilities for the fabrication of aluminum products even though Aluminum Limited owns plants abroad which process Canadian ingot and thus the incentive for the provision

of facilities for the manufacture of exported metal is lessened[11]. A considerable proportion of lead and zinc is used in the production of casting alloys which are immediately fabricated into the final product, there being no intermediate step, in most cases, corresponding to the semi-fabricated form of wrought products. Both lead and zinc are used in very small quantities in the semi-fabricated metallic state, less than 10% of the United States consumption of each of these metals is in the form of unalloyed mill products[12]. In the cases of lead and zinc and of nickel the Canadian consumption is actually so low that fabrication plants could only be economic if catering to an export demand, and thus it must be concluded that here the industrial basis is too slight to justify further manufacture.

For the exports of iron and steel the situation is different from that of other metals in that a large proportion of the exports, in terms of value, is actually in the form of highly, rather than partly manufactured goods. However, it is in the manufacture of iron and steel goods that the Canadian economy is lacking, for exports in this sector are only one quarter of the imports[13]. This apparent anomaly is due first to the fact that most of the manufactured metal goods are of iron and steel and secondly that it is less costly to transport the minor components in a manufactured product, as for instance the non-ferrous metals, to the place of fabrication of the major component than vice-versa. Canada manufactures a number of its iron and steel goods, and often exports in those fields that it does manufacture, but there is still a substantial area in which the economy is insufficiently developed to permit competitive production. This situation leaves a number of manufactured metal

goods that must be imported and an enlarged surplus of non-ferrous metals for export, even though some of these metals return in the imported finished goods as minor components.

The reasons for this situation cannot be considered in detail here, but it is mainly a question of overhead costs. The overhead costs for engineering products, as a considerable proportion of the manufactured metal imports are, can be divided here into two broad categories of which the first is design overhead and the second is manufacturing overhead. The detailed designing of a piece of machinery is costly, but, once complete, a second unit can be manufactured with virtually no design overhead; Canadian industry, if it attempted to build all its own capital goods, would in fact build a large proportion of very costly prototypes. This problem is only a matter of scale of production, and where a number of units are produced, either for a large domestic or for an export market, Canadian industry can compete effectively as it does in agricultural machinery.

The manufacturing overhead is also related to scale of production and includes, for the purposes of the present discussion, administrative and distributive expenses. Where the production of a large number of units is required, mass production techniques can bring about significant cost savings; these savings are only realised if a certain minimum output is achieved, however. For this reason Canadian subsidiaries of United States companies, even though they escape design overhead, cannot effectively compete with their parent company on a cost basis because their output is individually too small. Two further points should be noted. These two types of

overhead are most severe in their effect on two different sectors of the engineering manufacturing field: design overhead on capital goods and manufacturing overhead on consumption goods and consumer durable goods. The second point is that of this very considerable sector of Canadian imports, Iron and Steel Goods, only a small proportion is in the form of semi-manufactures and these include large structural sections, heavy plate and other specialised products which are manufactured on a scale which is large compared with the total Canadian market.[*]

Conceding the point that it will be some time before the economy has grown sufficiently to produce and to export more metal manufactures, so putting all its metal raw materials, both ferrous and non-ferrous, to better use, why cannot the metal exports be in a semi-manufactured rather than a crude or unmanufactured form as suggested on page 10? In addition to the factors cited for lead, zinc and nickel, where the Canadian consumption is too small to provide an adequate industrial basis, there is the matter of ease of communications between the supplier and the consumer of semi-fabricated metal products. The supplier of these products is required, by custom and need, to have available at short notice a very wide range of items corresponding to many dimensional specifications. If this supplier does not have an adequate range of products he is at a considerable competitive disadvantage. Canadian metal producers are placed in this situation in many instances.

[*]The reader is referred to Canada Year Book 1959, p. 622, which contains a tabulation of Canada's steel imports.

These difficulties can be overcome by establishing warehousing facilities at a favourable location close to the consuming center but in most cases, as the statistics show, this is found to be a costly procedure and usually the primary producer merely exports the refined, though unfabricated, metal[14].

A third factor in this respect is the import duty that the consuming country often imposes on the manufactured and the semi-manufactured metal over the crude or the refined metal. Table I-5 presents the duty rate on metal entering the United States in a number of forms. Also appearing in Table I-5 are approximate figures on the cost of converting the refined metal to the more manufactured form. In a number of cases the United States import duty amounts to a substantial proportion of the manufacturing cost up to semi-manufactured condition, although care must be exercised in the interpretation of these figures since these costs are greatly dependent upon the scale of the operation and on the physical properties of the metal in question.

TABLE I-5 Import Duty on Metals in Concentrates, Refined Metal and Semi-Manufactures on Entry to the United States (in ¢/lb metal).[16]

Metal	Concentrate	Refined Metal	Semi-Manufacture*	Approximate Cost of Fabrication[15]
Iron Ore	nil	.019	.7	1.4
Copper	1.70	1.70	2.95	15
Lead	.75	1.063	1.313	--
Zinc	.60	.70	1.00	11
Nickel	nil	1.25	9.5	38
Aluminum	--	1.25	2.5	13

*In most cases the semi-manufacture is a simple strip, sheet or rod in the hot worked condition.

It is evident that the difficulties facing a program designed to

maximise the proportion of metal exports in a manufactured form are formidable. In most cases the fully manufactured goods can only enter at even higher rates which in the United States range between 15 and 40%[16]. As already indicated, firms manufacturing engineering goods in Canada face considerable competition from abroad in the fields of capital goods and consumer durables. The markets for these goods are of necessity somewhat small for an underdeveloped country starting a program of forced industrialisation. However, there does appear to be some possibility that, if Canadian firms were larger, they could compete more effectively with foreign manufacturers. Elsewhere the market for some of these goods is simply too small.

In spite of these problems the Non-ferrous Metal Products industry employed nearly 25,000 persons and made shipments worth $415,000,000 at the factory. In addition, the Electrical Apparatus and Supplies, Iron and Steel Products and the Transportation Equipment Industries contributed importantly to the Gross National Product of the country, although the supply of the metallic raw materials consumed by these industries can only be regarded as a relatively minor factor in their development.[7]

To summarise briefly, the Canadian economy has expanded rapidly over the last few years and one of the most rapidly growing sectors has been that of the metals industries. The metals industries in Canada has now assumed major proportions, though a large part of the output is exported and that in mainly unmanufactured form.

This survey of the rôle which the metals and minerals industries play in the economy leads us to an assessment of the contribution, present and potential, of the area to which this thesis is devoted.

TABLE I-6 Value of Metallic Mineral Products from the Underdeveloped Areas of Northern Canada in the Year 1955[17].

Province or Territory	Net Value of Shipments $	Number of Employed	Value of all Supplies $
All Canada, all minerals	1,600,314,160	133,636	1,068,227,519
All Canada, metallic minerals	909,932,534	81,970	971,546,007
All Canada, metallic minerals less smelting	465,927,453	53,364	203,834,607
Northwest Territories	20,757,623	1,028	2,877,902
Yukon Territory	9,154,913	822	3,752,708
Northern Quebec*	33,400,000		
Pre-Cambrian Areas, metallic minerals (Estimated)	700,000,000	63,000	760,000,000

*Includes Labrador Iron Ore

The above table, Table I-6, shows that at present the underdeveloped areas of Northern Canada contribute very little to the total output of minerals. The metallic mineral output of the Yukon Territory is virtually limited to that of the lead-zinc-silver mines of the Mayo district and the placer gold of the Dawson area. The Northwest Territories is somewhat more productive with several lode gold mines in the Yellowknife area, four in operation at present. The Northwest Territories is also fortunate in having certain oil reserves. However, none of these mines in the Northwest or Yukon Territories is more than a relatively small-scale operation exploiting high-grade ores.

The iron mining development in New Quebec and Labrador is quite different from that in the Territories. Here a very large outlay was made to provide rail transportation, power generation facilities and docks as well as the equipment for the mine. Further-

more, although there is at present only one company exploiting ore deposits in this area, there is little doubt that within the next five years several other properties of similar proportions will be opened up[18].

Even though the exploitation of the mineral resources of the Northern areas has not progressed very far and, except in the case of iron ore in Northern Quebec, has not been the type of development that makes a significant contribution to the economy as a whole, the mineral production potential of the area has always held considerable attention. Thus mining companies have shown great interest in any steps taken by the Government or private agencies to provide transportation and other facilities.* Governments and political parties of various persuasions have all held themselves to be ready to assist or to initiate such programs of development. The principal reason for this interest is that much of the area is of a similar geological structure to that which does at present yield a very large proportion of Canada's metallic mineral output. Thus more than 50% of the area is outcropping rocks of the Pre-Cambrian formations similar to those which have yielded almost 80% of the metal output of Canada. A further portion of this underdeveloped area is of the Cordilleran structure which also yields considerable quantities of metals. (See the attached map.)

In spite of the general optimism about the mineral potential of the Northern regions of Canada, the actual, proven mineral

*Briefs to the Royal Commission on Canada's Economic Prospects.

reserves have not, in most cases, been measured. This lack of definite information is due to the cost of carrying out such work and to an uncertainty as to when development will be feasible, rather than to a lack of confidence that good reserves do exist.

Starting now with the plausible premise that large ore reserves of good grade do exist[19], let us consider why development has, in fact, been so slow. Many factors contribute to this situation, and among these are the climatic conditions and the paucity of transport and power facilities. Almost the entire region has a mean annual temperature of less than 32°F. and, except for the Yukon Territory, vegetation is scant or non-existent[20]. Climate thus offers no inducements and, in fact, conditions are so unpromising in these areas that both population and economic activity, except for mining*, is negligible. The total population of the Yukon and the Northwest Territories is a little over 30,000 while its area is more than one-third of the entire area of Canada. The situation in Ungava is little different from that of the Territories so far as climate and economic activity are concerned.

Transportation and power facilities have, reasonably enough, been somewhat neglected since there is no demand (in the economic sense) for such services. There is a railroad from Whitehorse to Skagway, a total of 110 miles long, and one from Seven Islands to Schefferville which is over 300 miles in length. Roads are also limited, there being only 2,260 miles of road throughout the entire

*Mining accounts for over 80% of the net value of production for these Territories in 1955.

area. The Mackenzie Highway, which runs from Grimshaw, Alberta, to Hay River on the shores of Great Slave Lake, is well constructed and maintained and is capable of handling heavy traffic for most of the year. The Alaska Highway which traverses northern British Columbia and the southwestern corner of the Yukon Territory on its way to Alaska, is only kept open during the summer months. The other roads, apart from being inadequate in extent, are of inferior construction.

A large proportion of the traffic in the Western and Eastern Arctic is handled by water transportation. A system of tugs and barges, of wharves and of overland portages has been developed so that freight can be transported from Waterways, Alberta, to Tuktoyaktuk on the Arctic Ocean. During 1957 nearly 200,000 tons of freight was handled by Northern Transportation Company Limited, a Crown corporation, and, in addition, further quantities were carried by the Yellowknife Transportation Company and the Hudson's Bay Company. Some shipping uses the Yukon River and, where feasible, the Arctic and Hudson's Bay coasts are served by ocean vessels. In terms of tonnage handled the Quebec North Shore and Labrador Railway Company which serves the mines of the Iron Ore Company of Canada in New Quebec is by far the largest carrier.

Energy supply utilities have been provided where these services are required and at present amount to a total of 50,000 H.P., a significant proportion of which was developed to support various mining operations. The potential power that might be developed amounts to over 4,000,000 H.P. in the Yukon Territory and in the New Quebec-Labrador regions. However, in the Northwest Territories

the power potential is much lower, due to the smaller precipitation rate, and is of the order of 800,000 H.P.[21].

Oil is available at Norman Wells in the Northwest Territories but production is for local consumption and has been of a sporadic nature during recent years. The oil and gas potential of the Mackenzie Basin and adjoining areas is extremely large[22]. The area is, on the whole, favourably situated for energy resources which, when the time is appropriate, could be developed to support a mining operation without undue cost. At present power is costly, but this is more the result of the small demand rather than a lack of potential[23]. Small, remote operations will always be at some disadvantage on this score.

The supply of water is adequate throughout the area since evaporation loss is low even where precipitation is fairly low.

Communications are, of course, greatly extended over an area as large as this, although radio and air travel have overcome many of the former difficulties. Communications could still be inadequate for certain types of industrial activity, but for mining operations, such as those considered specifically by this study, ample facilities could be provided promptly.

As already mentioned, the Government has shown considerable interest in the development of the Territories. Prominent among the activities of the Department of Northern Affairs and National Resources, and the Department of Mines and Technical Surveys, the two government offices concerned, is the encouragement of the development of mineral deposits in the inaccessible regions. Thus starting in 1952 the Geological Survey of Canada, a unit of the Department of Mines and Technical Surveys, carried out a series of aerial mapping

expeditions which covered much of the Districts of Franklin, Mackenzie and Keewatin as well as Ungava and Northern British Columbia. This work provides information which is of great value in the exploitation of mineral resources.

Government plans for the northern areas include the provision of road and rail facilities. Though nothing definited has been formulated for the latter, roads are to be built both through the Federally administered Territories and through the northern parts of several of the Provinces.

There are, at present, Government provisions for the encouragement of mining enterprises anywhere in Canada. These benefits, which include corporation tax relief and Government purchasing schemes, apply equally to the underdeveloped areas and elsewhere.

A further type of government intervention that might be contemplated, with a view to accelerating the rate of Northern development, is the establishment of Crown corporations to exploit the mineral resources directly. This action has already been taken in one case, the Eldorado Mining and Refining Company (uranium and radium), but there is no indication that such a step will be taken again. The indications are rather that the Government holds itself ready to assist, in some measure, in the provision of transportation facilities.

In conclusion it may be said that the Canadian economy is growing rapidly and that a very important sector of the economy is the mining industry; furthermore, exports of mineral products are very important to Canada and are significant internationally. The question of the form of Canadian metal exports has been discussed and, though

several of the relevant factors were indicated, no conclusion can yet be drawn as to what trends will be established in the future.

The Northern areas were seen to be poorly developed in many aspects and, although the mining industry is even now very important to these regions, it is still very small. Business and Government activities in the area were reviewed and it is concluded that the preparatory work for the exploitation of the mineral resources is well advanced. The further development of these resources will need the markets which would provide the incentive for the production of metals under the unfavourable conditions prevailing in the area, or the discovery of an exceptionally rich ore deposit. So far as the latter is concerned it is of a matter of experience that intensive exploration and prospecting take place only when market conditions are favourable.* The chapter that follows covers one of the aspects of the future market for a number of metals.

*Development of the uranium industry under the stimulus of premium prices.

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Chapter II

The development of the mineral resources of Canada's Northland will depend very greatly upon the demand for these products in the years to come. This factor is likely to be dominant even if development is stimulated by direct or indirect Government assistance. It is to be anticipated that this demand will be implemented through a price system and the extent to which the metallic minerals will be mined in any area will depend also on the overall production costs encountered in that area. The possible cost of production of metals from the Canadian North will be considered later. Here the problem of the demand for these commodities in the future will be appraised.

The forecasting of the consumption of a commodity for a period of twenty-five years, as is under consideration here, is fraught with many difficulties. First is the problem arising from the fact that supply and demand are inter-related; the problem in reality is that of predicting demand at various price levels. However, without in any way minimising the importance of the problem, for the time-being it is assumed that the present price structure remains unaltered. When an evaluation of the supply position is also complete, both aspects of the market will be taken into account and the appropriate modifications will be made for each estimate.

The difficulties of forecasting future consumption of the metal products that might, potentially, be mined in the Canadian North are mitigated to a degree, however, by two further considerations. It seems very likely that Canada will remain a large exporter of metals and metalliferous ores throughout the next twenty-five

years. A second factor that is of assistance in the forecasting of the future metal consumption is that refined metals are among the few remaining commodities for which product differentiation has made little progress.

These two factors make it justifiable to relate the demand for Canadian metal products directly to world demand. Furthermore, it is relatively rare for a company manufacturing consumer goods to mine its own metals and this general lack of a highly developed vertical integration means that metals and metal ores are among the most important commodities entering national and international trade[1]. An active demand for metals in one part of the world can, and likely will continue to, bring forth supplies from wherever they are available so far as balance of payments and tariff restrictions allow.

World demand will thus be used as a basis for assessing the market for the mineral products from the Canadian North, since directly or indirectly these commodities can enter international trade if costs are competitive.

This chapter is arranged so that the published material available will be considered first and, subsequently, each of these forecasts will be evaluated. On the basis of these data and any other information that appears to be relevant, an attempt will be made to arrive at some conclusion about the future consumption of the selected metals and minerals.

During the past ten years a number of mineral and other strategic commodity resource surveys have been made. These have often been made on behalf of governments, as for instance the

"Report to the President of The President's Materials Policy Commission" and the report of the "Royal Commission on Canada's Economic Prospects". (Subsequently these two reports will be referred to, respectively, as the "Paley Report" and the "Gordon Report".)[2,3] Both these reports cover approximately the same period and, although the first was prepared about five years prior to the second, each forecasts the situation over the next twenty-five years (Table II-1).

In addition to these two comprehensive surveys, studies have also been conducted for particular individual commodities. Thus there is a series of such forecasts prepared by W.P. Shea and published in the Engineering and Mining Journal. These estimates are presented in Table II-2 together with some of the other predictions that have appeared in the technical press from time to time.

TABLE II-1 Comparison of the Forecast World Consumption of a Number of Mineral Products According to the Paley and to the Gordon Reports.

Commodity	Actual Consumption				Paley		Gordon	
	1950 tons	1955 tons	1958 tons	'55 as % Of '50	1975 tons	'75 as % Of '50	1980 tons	'80 as % of '55
Iron Ore '000,000	242	340		140.5	418	173	560	165
Nickel '000	158	272	330	172	316	200	650	239
Copper '000	2,761	3,383	4,091	122	4,260	154	5,500	162.5
Zinc '000	2,341	2,927	2,942	125	3,770	161	3,900	131
Lead '000	1,837	2,178	2,313	118.5	3,270	178	2,800	129
Aluminum '000	1,650	3,240	3,906	196	8,500	515	24,250	756

Note: The Paley estimates did not originally take into account the Soviet bloc consumption and thus the figures have been modified appropriately. See page 32.

To facilitate a comparison between these various estimates a graphical presentation has been prepared and these appear in Figures II-1, II-2, II-3, II-4, II-5 and II-6. For comparison only, the metals iron,

nickel, copper, zinc, lead and aluminum have been considered. Later discussion will demonstrate, it is believed, that these metals are likely to be most significant in the development of the Canadian North and that, if required, the factors considered for these mineral products can be extended to other products.

TABLE II-2 Miscellaneous Estimates.

Estimator	Metal* (tons)	Date of Estimate	Predicted Consumption 1960	1975	1980	
W.P. Shea[4]	Copper (m)	1955	3,750	5,000	--	
W.P. Shea[5]	Lead(m)	1956	3,200	3,500	--	
W.P. Shea[6]	Zinc(m)	1956	3,100	4,000	--	
A.W. Knoerr[7]	Iron Ore (mm)	1957	480	800	920	
F.C. Fearing[8]	Nickel(m)	1956	280	510	600	"Free World"

It will be noted that, although there is good agreement between the estimates in some cases, elsewhere large discrepancies appear. However, before discussing each commodity in detail, a brief description of the various methods employed in forecasting the future demand for metals will be attempted.

The Paley Report estimates were particularly directed to the prediction of the future consumption of metals by the United States. It was recognised that substantial quantities of these mineral products would have to be imported, and thus the anticipated consumption abroad would also have to be considered. However, though adequately handled, consumption on a world-wide basis was not studied in such detail as was that of the United States.

The method used for estimating the future consumption in the United States for a particular commodity was based on preliminary estimates of the growth of the working population and of the Gross

*Note: "m" has been used to indicate thousands and "mm" millions.

National Product[9]. This preliminary estimate was made by assuming that productivity, expressed as a ratio between output and man-hours employed, would increase at a slightly higher rate than in the past: a rate of 2.5% per year being employed rather than the historical 2.1% per year rate. It was also assumed that working hours would be on an average 15% less than in 1950 while the working population would grow 82 millions, an increase of 27% over the twenty-five year period considered. These computations showed that the Gross National Product of the United States would grow at about 2.8% per year (compounded annually) to double over the period 1950 to 1975. The next step was to estimate the growth anticipated in the major end-use commodities and services. The end-uses considered were plant and equipment expenditure, residential construction, automobiles, appliances, telephones, farm machinery, railroads, printing and publishing, paints, shipbuilding and "fast-growing" uses such as aircraft, electronics, plastics, etc. Growth in each of these end-use sectors was estimated in relation to the total increase in the Gross National Product over the twenty-five years. Table II-3 shows the factors used in each case. Where the growth of consumption in 1975 over that in 1950 has been estimated, the judgement of the forecasters had to be employed to a significant extent.

TABLE II-3 Growth between 1950 and 1975 in Aggregates and Major End-Uses. Paley Report.

Item	Growth '75 over '50
Population	27%
Labour Force	27%
Gross National Product	100%
Gross Private Domestic Investment per year	40%
Construction per year	30%
Producers Durable Equipment per year	15%

TABLE II-3 Continued.

Item	Growth '75 over '50
Consumers Durables per year	50%
Passenger Cars per year	50%
Appliances per year	40%
Automobiles and Trucks per year	15%
Dwelling Units per year	50%
Automobiles in Use	75%
Trucks in Use	150%
New Railroad Equipment per year	100%
Agricultural Machinery per year	0%
Telephone Equipment per year	0%
Printing and Publishing per year	75%
Paints per year	50%
Shipbuilding per year	0%
Aircraft, Plastics, Insecticides etc. per year	400%

Note: Exceptional conditions in 1950 were taken into account, explicitly, where possible.

On the basis of the consumption of each metal in each end-use sector in 1950, the consumption in 1975 was estimated. Table II-4 sets out the three steps involved in this method of forecasting the consumption of metals in 1975.

TABLE II-4 Method of Forecasting U.S. Consumption of Metals in 1975 as Used by the Paley Report[10].

Step	Factors Used	Factor Predicted
One	(i) Labour Force (ii) Productivity of Labour (iii) Working hours	Gross National Product
Two	(i) Plant and equipment, residential construction, automobiles, appliances, etc. (ii) Gross National Product	End-use consumption
Three	(i) Quantity of metal used in each end-use sector in 1950 (ii) End-use consumption	Metal consumption

For industrial nations other than the United States the future Gross National Products were estimated on the basis of anticipated population growth, working hours and labour productivity

over the next twenty-five years. It was then suggested that the total demand for a particular metal should be calculated as follows: "for each doubling of the gross national product the percentage of their total demand will be higher by 10% than the projected increase in the United States"[11].* Allowance is made for scrap consumption and the actual increases for a number of metals are listed in Table II-5 below. The procedure described above applies to France, West Germany, Italy, Finland, Sweden, Norway, Denmark, Belgium, Holland, Luxembourg, Portugal, Spain, Austria, Greece and Yugoslavia taken together, United Kingdom, Canada, Australia and New Zealand, and Japan. For the underdeveloped countries it was assumed that the consumption growth rate would be three times that of the United States although in most cases the figure was adjusted so that the "Free-world total" came to a full number.

In the study that follows the world consumption of metals is of concern rather than that of the free-world alone as was the interest of the Paley Report. To apply the concepts and philosophies of the Paley Report to the world situation two adjustments have been made in the calculation of the future world consumption figures presented in Table II-1. Thus the total world output in 1950 was used as the estimate base rather than the free-world total and the total world consumption figure was then multiplied by the factor that had been derived for free-world countries excluding the United States. By these methods the considerable consumption of

*Both of these factors were selected "arbitrarily" according to the Report. In the first case increased rate was intended to compensate for the abnormally high purchases of consumer-durables during the Paley datum year, 1950, and in the second for present low living standards.

the Soviet-bloc countries was taken into account, while the demand of reconstructed Europe was accommodated without violating the precepts of the Paley study. The totals in Table II-1 thus include an estimate of the consumption of the U.S.S.R. and the Soviet-bloc countries.

TABLE II-5 Factors Used in Forecasting the Consumption of Metals in the Paley Report (see pages 31, 33 and 65).

	Estimated % Increase of 1975 over 1950						
Country	G.N.P.	Iron Ore	Copper	Lead	Zinc	Nickel	Aluminum
United States (total)	100	54	45	61	38	100	358
Canada	104	75	52	68	50		
Europe (excl. United Kingdom)	90	65	45	58	43		
United Kingdom	62	45	31	40	30		
Australia and New Zealand	158	114	79	103	76		
Japan	220	158	110	143	106		
World*		73	54	78	61	100	415

*These factors were used for calculating world consumption including the Soviet-bloc.

The research staff employed in the preparation of the Gordon Report made most of their estimates on the basis of a constant percentage increase of consumption each year. The percentage increase, which is a compounded rate of growth, varied from metal to metal depending upon the judgement of the staff as to the appropriate figure[12]. The annual increase rate for each of the metals under consideration is presented in Table II-6 together with the historical growth rate computed by the staff. The factor decided upon in each case was applied to the 1955 consumption figures.

The estimates that have been published independently of the Paley and the Gordon Reports are contained in Table II-2 and have also been included in the appropriate figures.

TABLE II-6 Factors Used for Forecasting the 1980 Consumption of Metals by the Gordon Report.[12]

Metal	% Increase of 1980 over 1955	Historic Rate %/year	Estimated Rate %/year
Iron Ore	65	2	2
Copper	62.5	3	1.9
Lead	29	1.5	1.0
Zinc	31	2.5	1.1
Nickel	139	5.0	3.5 (5.0 for non-military)
Aluminum	656	9.0	8.4
G.N.P.	200	5.2	4.0 - 5.0

Mr. Shea's estimates for copper, lead and zinc are based on past growth rate performance. Apparently an extrapolation is made on the plot of consumption vs. date on semi-log paper using the logarithmic scale for the consumption in tons per year. The extrapolation is sometimes a straight line and on other occasions appropriately curved. Mr. Shea also makes a comparison between the dollar value of metal consumption in the United States and the product of the Index of Industrial Output in the United States and the Index of Wholesale Prices. He has obtained a number of good correlations for these two sets of data suggesting that the use of these particular metals has grown fairly consistently with the level of industrial output. Unfortunately, Mr. Shea does not explain his method of forecasting.

Knoerr and Fearing have made estimates on the basis of world population increase and a "use" factor. Thus the mean consumption trend was assessed over a short period of years, 1950 to 1957 for iron ore and 1947 to 1956 for nickel, and the per capita use was calculated for selected dates. The "use" factor was then set up as a parabolic function with time so that per capita consumption at a future date could be calculated. The parameters of the parabolic function were calculated from figures available on past per capita

consumption trends though the fit of the data cannot be considered to be very reliable due to the short periods of time over which stable growth conditions prevailed. Presumably a parabolic function was selected because it fitted the data, from a mathematical viewpoint, better than other functions. The final total consumption of either iron ore or nickel was then computed on the basis of United Nations' population forecasts and this per capita "use" index.

Exponential growth curves, such as the Gompertz and the Pearl-Reed, have been suggested for predicting the consumption of chemical products but attempts to follow a similar procedure for metal consumptions have not been very successful to date[13,14,15]. However, a detailed consideration of these methods is reserved for Chapter III.

Reference to Figures II-1 to II-6 shows an order of magnitude agreement between the various estimates. A detailed enquiry into these discrepancies is justified since such a procedure may provide a guide to more reliable methods.

First comparing the Paley and the Gordon Report methods: the method used by the Paley Report was quite thorough and was "atomistic" in its approach, if such a term can be used. By assessing the growth in the Gross National Product and relating each of many sectors of the economy to this, growth of expansion or contraction of various industries was assessed. The metal consumption was then calculated for each industrial sector. This procedure was followed for the United States and was modified for the other countries of the world using a less detailed procedure (note the assumptions used to include the metal consumption of the Soviet-bloc). The

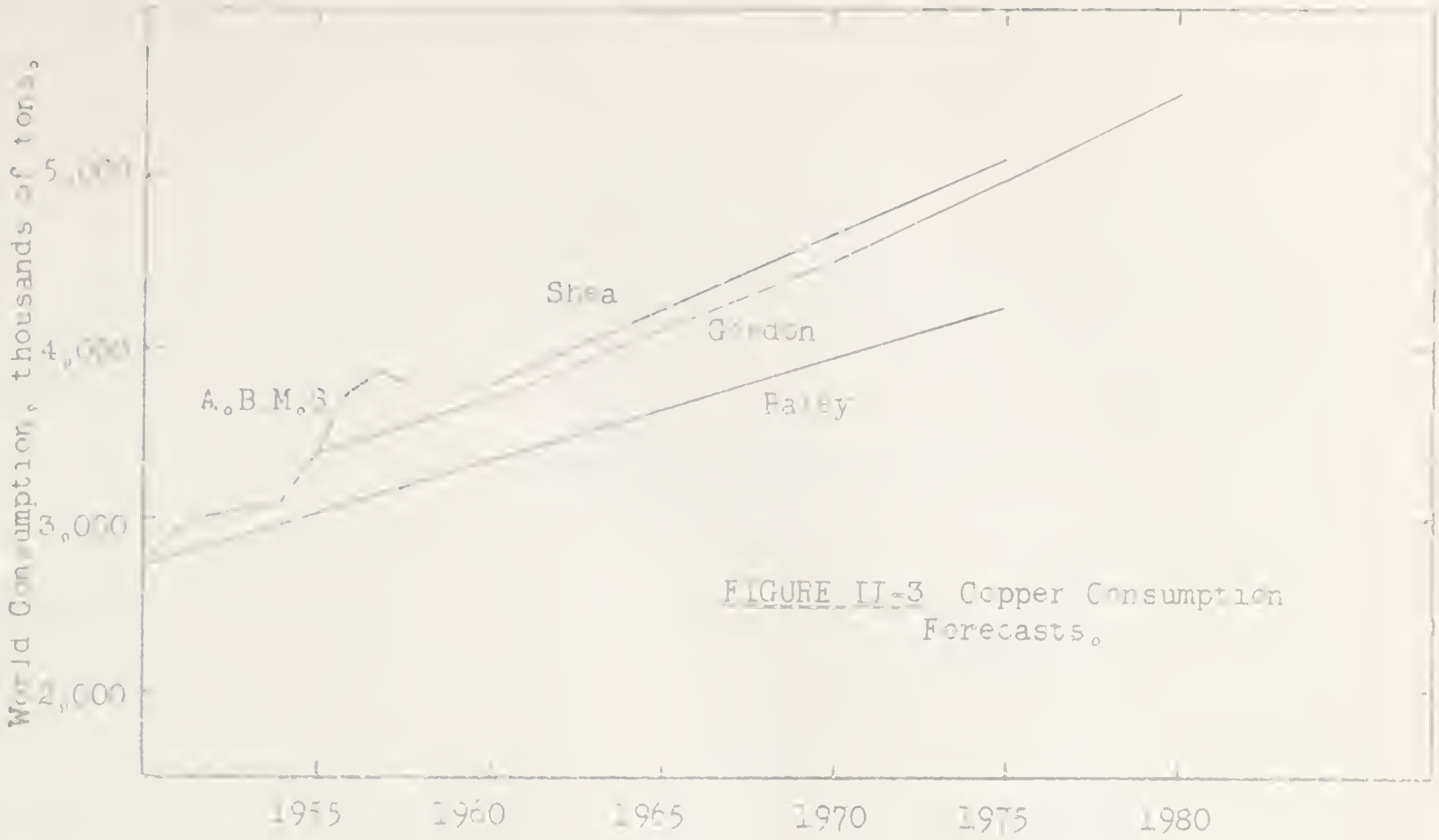

FIGURE II-3 Copper Consumption Forecasts.

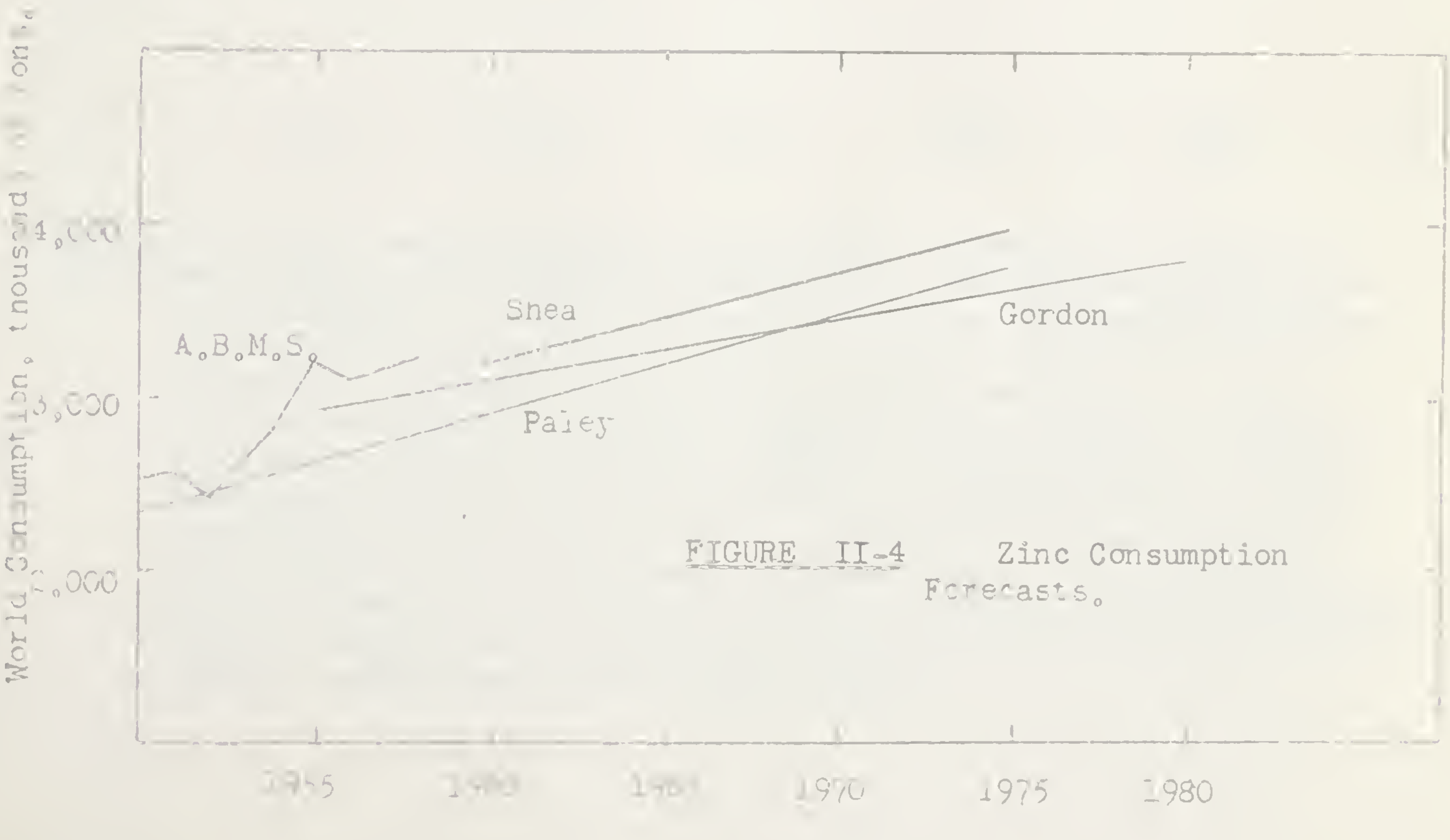

FIGURE II-4 Zinc Consumption Forecasts.

FIGURE II-5 Lead Consumption Forecasts

Note: The Paley Report suggested that the consumption of lead in batteries, oil refinery products and insecticides would grow very rapidly, as would consumption in the non-industrialised countries. The researchers for the Gordon Report, however, expected a gradual deterioration in the position of lead. It is interesting to note, also, that the Paley Report predicted an equal or greater rate of growth of consumption of copper than zinc in all countries except the United States and the un-industrialised countries. In the latter it was suggested that the rate of growth would be more than five times that in North America and Europe and it is this very large increase that brings about a greater world-wide growth for zinc than copper during the period 1950 to 1975.

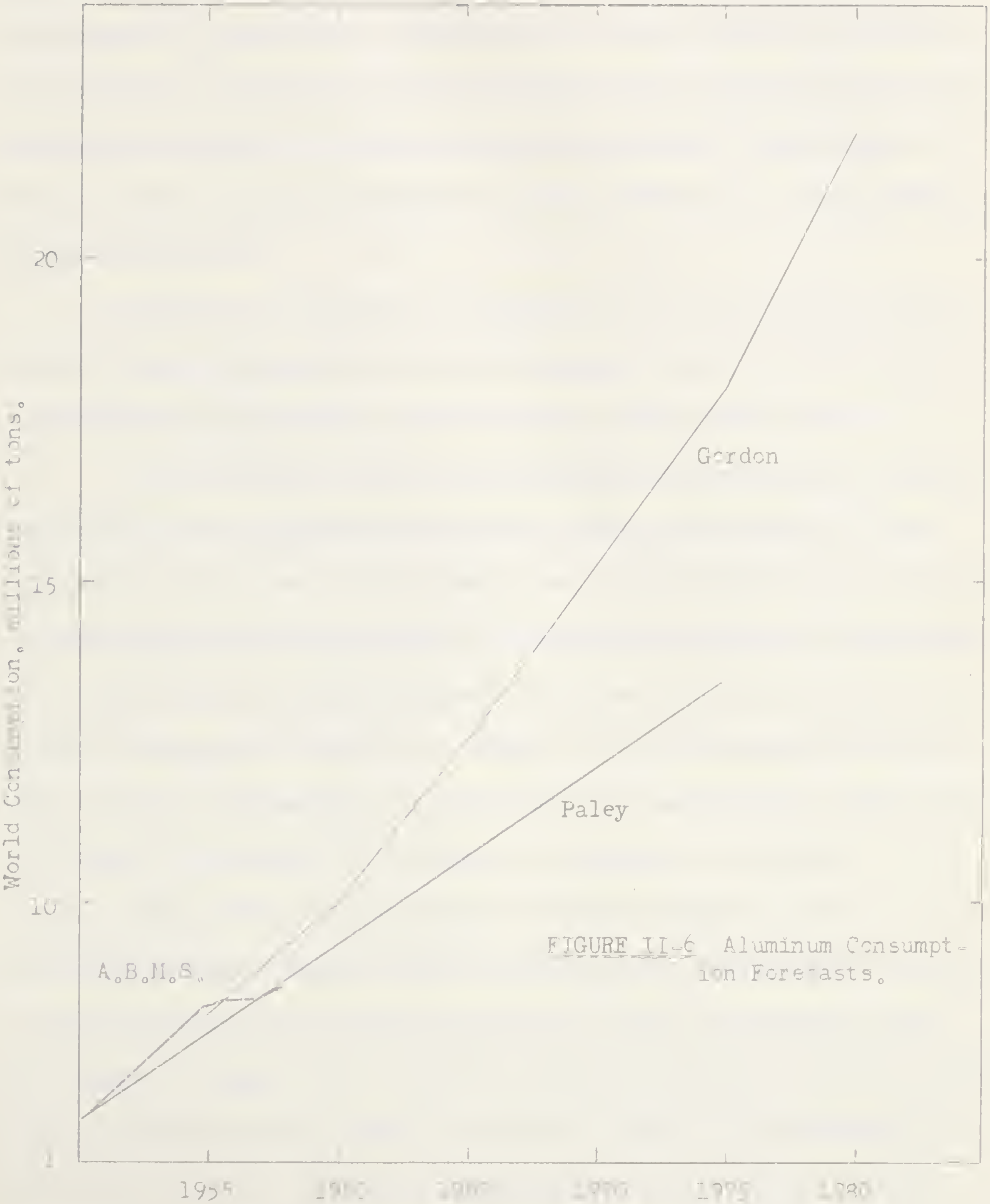

FIGURE II-6 Aluminum Consumption Forecasts.

Gordon Report used a compound growth rate method based on a historical rate modified appropriately by the Commission.

Reference to Figures II-3 and II-4 shows a general order of agreement between the two estimates for copper and zinc. The two estimates for the future consumption of nickel shows a much greater divergence, as is illustrated by Figure II-2; thus the Paley Report predicts a growth of 100% over the period 1950 to 1975 while the Gordon Report suggests a growth of about 140% from a significantly higher base year.

The rate of growth of consumption of iron ore was similar in each case, although the lead consumption rate was considerably lower for the Gordon than for the Paley Report.(see page 35c).

It is believed that such discrepancies as do arise relate entirely to the adjustments that were made on the basis of the judgement of the two staffs. There was a very significant difference between the metals consumption of the five-year periods 1945-1950 and 1950-1955. During this second five-year period the growth of nickel consumption amounted to 72% of the 1950 consumption while the iron ore consumption rose 41% over the same period. Reference to Table II-1 reveals the growth in consumption predicted by the Gordon Report for zinc and copper was less rapid and that for lead was significantly slower than forecast by the Paley Report. Moreover, Paley expected lead consumption to grow more rapidly than the usage of copper and zinc. The predicted rate of growth in aluminum was very great in all cases, as was the actual growth during the the period 1950 to 1955 and, although the Gordon Report showed a greater rate of growth than did the Paley,

it is hard to attach much significance to this fact.

It appears that the rate of growth during the period 1950 to 1955 greatly influenced the staff of the Royal Commission in that it caused them to choose a faster rate of growth for nickel and aluminum and a slower rate of growth for lead than had been selected five years previously. Furthermore, the choice of the year 1955 as the basis for the extrapolation is hard to justify for it implies that 1955 was a "typical" year. It can, of course, be contended that those compiling the Paley Report were just as influenced by conditions at that time as was the staff of the Royal Commission, though in the case of the former a wider range of factors was taken into account.

The forecasts prepared by Shea are in very good agreement with those in the Gordon Report. This agreement is particularly striking with copper and zinc but less apparent with lead. One reason for these discrepancies is believed to be due to the fact that the Royal Commission estimates are based on new or mine lead and other metals, while Shea includes the consumption of secondary metals. Discrepancies due to scrap consumption are much less important for copper and zinc than for lead.

The estimates prepared by Fearing and Knoerr show good agreement with the Gordon Report's nickel estimate and very divergent results for iron ore. However, it is believed that part of this difficulty is due to the very short period that was used by Knoerr to calculate trend figures for iron ore consumption. During the period 1950 to 1957 iron ore production and consumption increased very rapidly to supply Western Europe. This rapid increase somewhat

distorted Knoerr's "use" index so causing him to predict a rate of growth of the order of 3 1/2% per year as against the historical rate of 2%. Both Paley and Gordon Reports used a rate of growth of about 2% per year. A rate of increase of about 3 1/2% per year was obtained by Fearing for nickel and this rate was close to the historical rate and the figure used by the Gordon Report. The implications of these data are that a rate of 3 1/2% per year may be acceptable for nickel but not for steel. This topic will be taken up more fully later.

The Paley Report figures fell short of the actual growth over the five years 1950 to 1955 due mainly to an under-estimation of the rate of growth in Europe. The very high rate of increase in consumption in Europe was partly but not fully anticipated, see Table II-5[16]. The actual increase in metals consumption in Western Europe and the United States are compared in Table II-7.

TABLE II-7 Consumption of Metals in Western Europe and the United States over the Period 1950 to 1955 (new metal).

	Iron Ore	Copper	Zinc	Lead	Aluminum
Increase of 1955 over 1950 in the United States	12%	5%	8.6%	-8.5%	96%
Increase of 1955 over 1950 in Western Europe (excl. U.K.)	42%	70%	46.0%	28.0%	186%
Western Europe (excl. U.K.) as a % of the United States in 1955	61%	71%	60.5%	73.5%	34%

Speaking generally, however, a certain annual percent increase in consumption has been assumed or implied by each of the estimators and these assumptions have been supported by material and investigation to justify the selection of the particular growth rate. Paley relates

commodity forecasts to a 2 1/2% per year increase in the Gross National Product of the United States, and, in fact, all other estimates presented stem from this basis. The Gordon Report baldly selects an annual percent growth rate for each metal based on historical rate of growth modified at the discretion of the Commission. Shea extrapolates either with a constant percent increase each year or with a slightly diminishing rate, while Fearing and Knoerr have a slightly increasing annual rate of growth.

It is now appropriate to determine the factors that are likely to influence the use of a material, here a metal, over a period of time. We might also consider whether a mathematical relationship might be developed to encompass these factors, though it is anticipated that there is no likelihood of devising a useful mathematical function that can effectively allow for political and technological changes. However, these difficulties are minimised when a metal long established in commercial application is considered, for here technical change and innovation is likely to have less impact than with a metal not in common usage. Again, though political changes may affect the consumption of a metal in one political area, by taking world consumption as a whole, the effect of such events is likely to be lessened over a period of time.

Although it is not possible to develop an exact mathematical function to forecast the consumption of a particular metal in the future, it is possible and useful to identify certain stages in the growth of the consumption rate. Thus there is an early period in the growth of the use of the metal, before it is used in appreciable quantities, when technical matters dominate the situation. Even

though a method of production and refining has been devised and there are uses to which the metal can be put, an impasse prevails. In this situation the metal cannot be used for many suitable applications because it is too costly and, on the other hand, it cannot be produced cheaply until a certain volume of production is attained. This impasse can be overcome by a technical innovation that lessens the cost of production or that causes the metal to become useful in applications where high costs can be tolerated. The impasse can also be overcome by massive investment in production facilities with supported purchase prices until the metal can be marketed in the usual way. Both of these methods were used in the development of titanium production facilities for defense work in the United States a few years ago[17].

This first period in the growth of consumption is typified by wide fluctuations in output which may persist for many years. Thus for both nickel and aluminum, periods of up to 50 years were needed before a fairly regular annual output was maintained.

The second identifiable stage is when the consumption of the metal is growing rapidly, more rapidly than the Gross National Product of an industrial country, for example. In this case the metal is either filling a place that did not previously exist, or else it is replacing some other material or metal. During this period consumption is beginning to amount to a significant total and investment is likely to be large in comparison to the value of the annual out-put of the industry.

A third stage appears when the rate of consumption of the metal follows the growth of the economy as a whole; the metal has

an established place and use in the technology and commerce of the country.

A fourth stage can, presumably, be identified when the use of the metal increases less rapidly than the economy as a whole and ultimately the total consumption falls.

Metals that are in the first stage of consumption growth are of little interest in a study such as this, since their contribution to an economy is likely to be quite small. Moreover, it is often the case that the processing and refining of the ore is an important stage in the operations and can best be carried out in some industrialised area. For this reason none of the "new" metals were included in this study of the potential growth of the minerals industry of the Canadian North.

Nickel and aluminum are probably both in the second stage of growth - that is to say the consumption rates of these metals are growing faster than the Gross National Product in industrialised economies.

Zinc, copper and iron ore appear to be growing in consumption at about the rate of growth of the economy as a whole and thus these metals are regarded as being in the third stage of growth. Of the metals considered here, lead alone appears to be in the fourth category where the consumption of the metal is growing less rapidly than the economy as a whole. In fact, here the metal is being replaced by other materials to a significant extent.

It is fairly evident that the possibility of developments around metals in stages two and three are likely to be of most value to an economy as a whole. Those at the first stage are not in large

enough volume to be of significance in an economy over the period considered here, while those in the fourth stage are often faced with vigorous competition on markets limited artificially by import tariff and quota regulations.* This idea that the consumption of a metal follows a growth curve, though interesting, may not alone contribute greatly to the effectiveness of a forecast of future consumptions.

Let us then examine briefly the possibility of dividing the consuming centers of the world according to their stage in economic development and see if this, combined with the degree of technical development of a metal concerned, can provide an alternative basis for a consumption forecast. Essentially, an analysis such as this depends upon the assumption that growth of demand for a metal can be summarised by an equation thus:

$$c = f(G, a, b)$$

c = Annual consumption of the metal considered
G = Gross national product of the consuming country
a = State of technology in the country concerned (this will be related in a general way to the G.N.P. per capita)
b = State of technical development of the metal.

The reason that the particular form has been selected for this equation is that it is believed that the consumption of a metal may depend upon two types of functions. Thus the factor "a" is related to the degree of development of an economy (- agricultural or industrial, traditional or progressive -) while "b" is intended to cover the technical status of a metal use. The consumption of

*In those cases where slackening demand causes surplus output or output capacity.

metals such as tantalum and hafnium, and even nickel and aluminum, tends to be restricted except where an industrial complex of considerable sophistication exists. Thus the value of "a" for a particular metal depends upon the Gross National Product per capita and upon other characteristics of the economy of the country under consideration. If a country supports a significant military establishment, the consumption of the new metals as well as the traditional is likely to be higher than if such expenditures are kept to a minimum. Similarly, if an underdeveloped economy pursues a program of industrial development, which uses metals, rather than one of increasing agricultural efficiency, which is less dependent on machinery, the pattern of metal consumption is likely to be different.

Some metals are being progressively displaced by other materials, as for instance lead (a value for "b" of less than one), while others are replacing established materials or creating new applications for themselves, as is aluminum (a value for "b" of more than one). These distinctions, though conceptually interesting, may not always be easy to identify. Thus, for instance, the consumption of steel in the United States has been increasing at a rate of about 2% per year, while the Gross National Product has been increasing at the rate of 3% per year for the last 50 years; there is very little evidence that steel is being displaced by any other material; in all probability the lower rate of increase in steel consumption is due to the more highly manufactured state in which commodities are now marketed and to disproportionate growth in the service sector of the economy.

The next step is to suppose that the world can be divided into political groups each of which has a characteristic or stage

of development. A suggested grouping is presented in Table II-8 below.

TABLE II-8 Division of the World into Categories According to the Degree of Development. (U.N.)

Country	G.N.P. in 1957 $ billions	G.N.P. per Capita $	Rate of Change of G.N.P. per year[20]
United States	440	1,970	2.7%
United Kingdom	50	810	2.7%
Canada	23	1,340	2.7%
Western Europe (excl. U.K.)	160	610	5.0%*
Japan	23	218	5.0+%**
Underdeveloped Countries***	125	(100)	--
Soviet Countries	--	--	5.0%

*For E.E.C. countries[18]

**See reference 19

***Appendix II

Reference to this tabulation and to Figure II-7 shows how growth in Gross National Product might be related to metals consumption. In the Western European countries it is apparent that in a number of cases those starting with relatively low standards of living in 1950 grew much more rapidly than those with a higher standard. Thus the rate of growth was significantly slower in Belgium and Luxembourg (and the United Kingdom) than it was in West Germany and Italy[21]. Furthermore, it appears that countries that have already attained a high consumption of metal per capita, and a high standard of living, show slower rates in metal consumption increase than those countries catching up. The annual increase in metal consumption of the Western European countries, in a number of cases, was as rapid as the growth in Gross National Product, while in the United States the rate of growth of

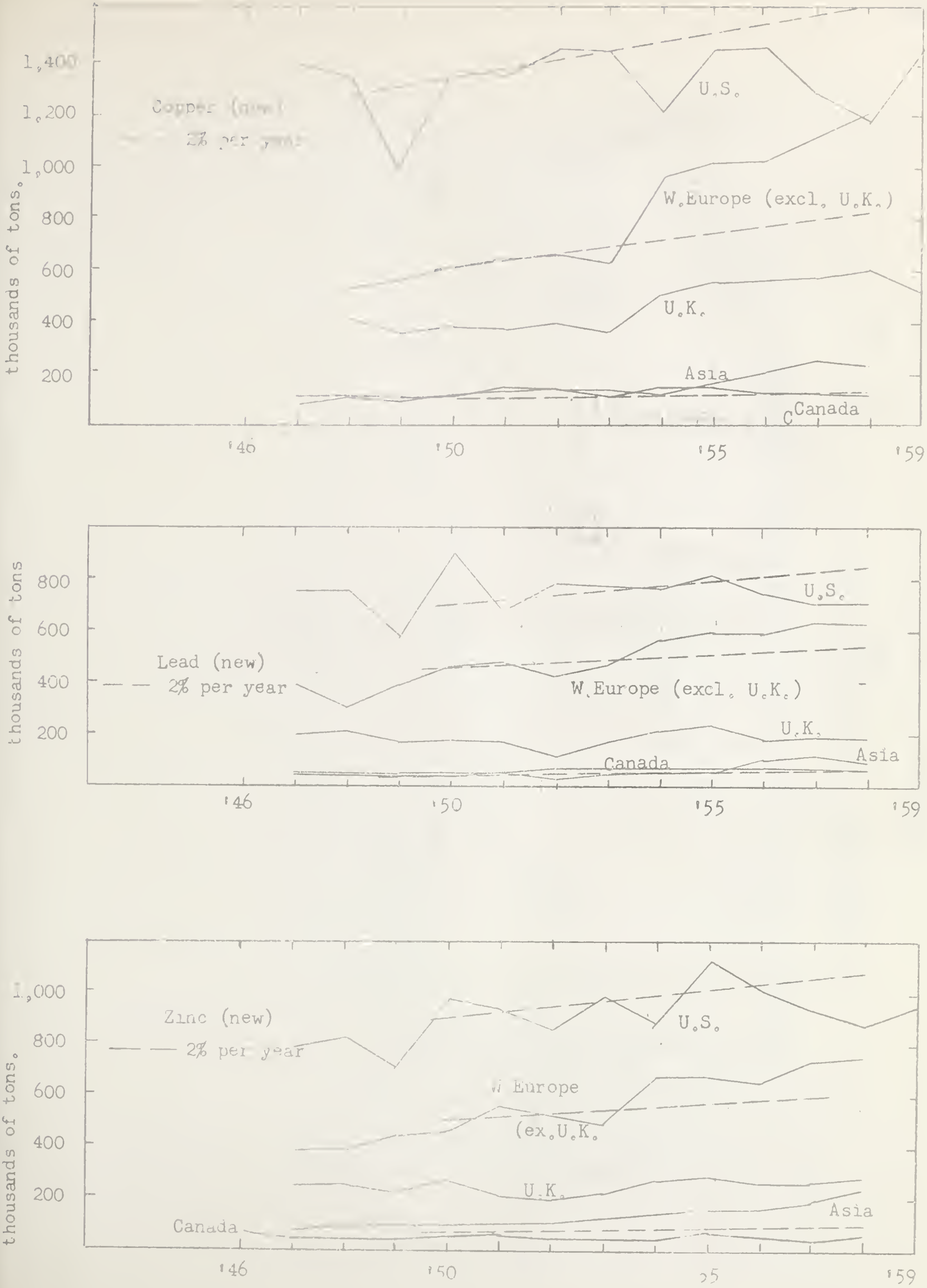

FIGURE II-7 Consumption of Metals in Recent Years

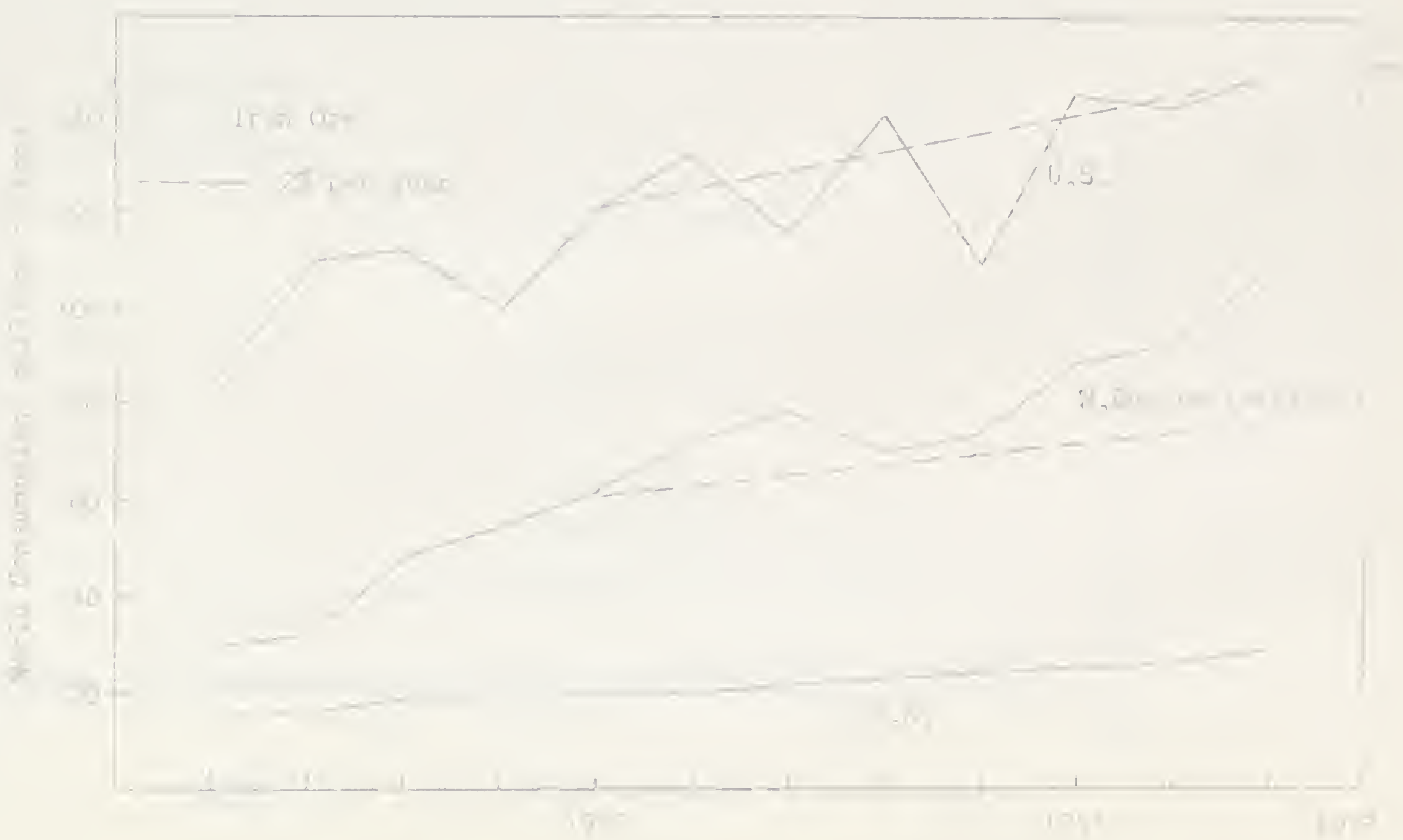

FIGURE II-

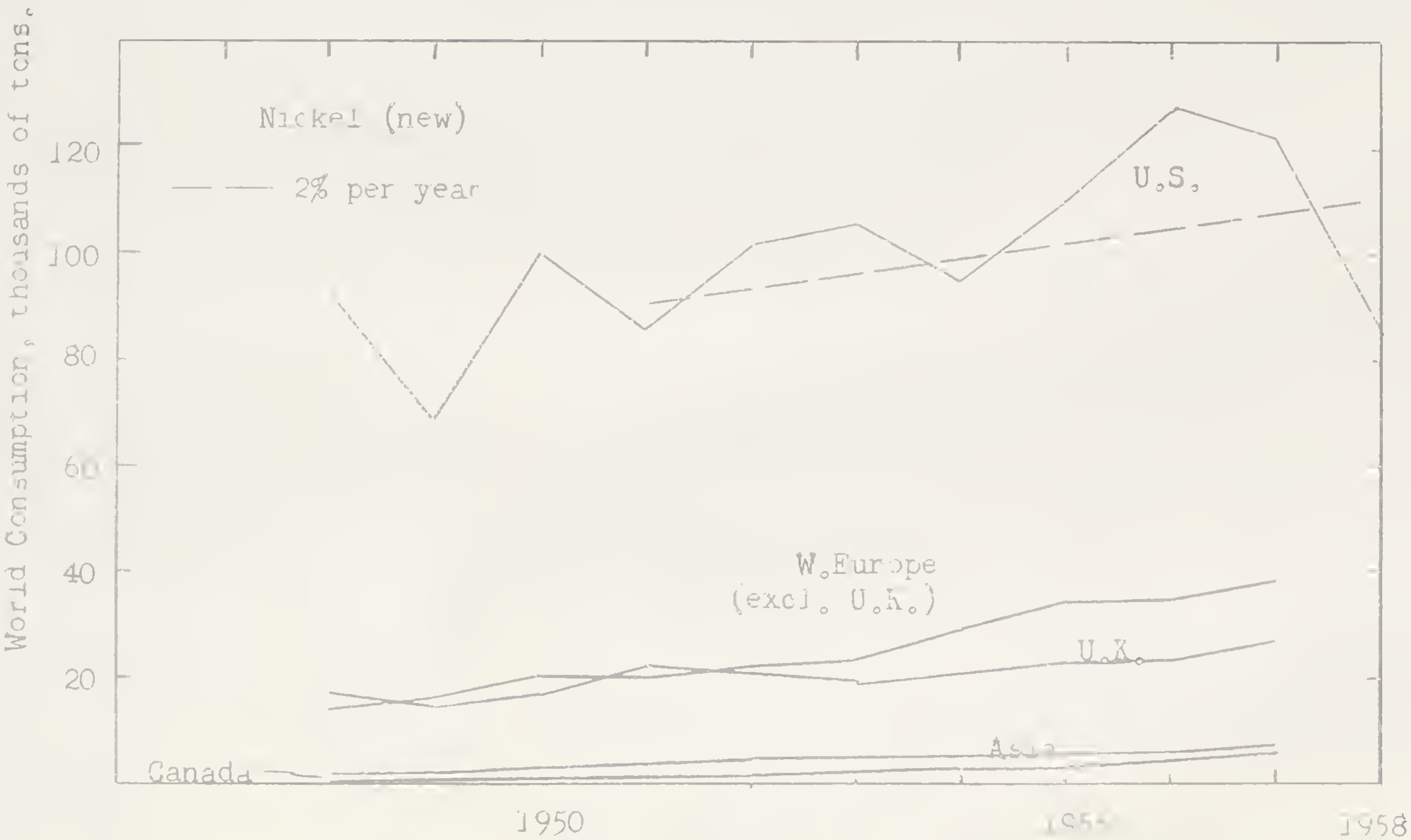

FIGURE II-7 Consumption of Metals in Recent Years (cont.)

FIGURE [illegible] Consumption of [illegible]

metals consumption was, on the whole, slower than the growth in the Gross National Products (see Table II-9). A further matter for conjecture in this respect is whether or not the per capita Gross National Product and metal consumptions in the United States could in any way represent a plateau or ceiling to the European economies. If the rates of Gross National Product growth presented in Table II-8 are maintained, the standard of living in Western Europe will be close to that of the United States by 1980. It seems unlikely that the United States will be overtaken by Western European countries due to the very considerable fuel and other natural resources that country still has. North African oil might, however, have a very significant effect on the future of Europe. It seems reasonable to suppose that in the years to come the disparities between the wealth of nations are likely to be less acute and that, though the United States will probably stay in the lead, greater homogeneity in terms of industrial development, availability of capital, and the skills of labour, will develop.

Reference to Table II-9 shows also that the apparent consumption of metals in the United Kingdom and West Germany are, except for aluminum and steel, as high as those in the United States even though the standards of living are significantly lower. This high apparent consumption of copper, zinc and lead is ascribed to the relatively large exports of machinery from West Germany and Britain. The machinery exports of Great Britain and West Germany are each about half that of the United States', while the populations are in the ratio of almost 3.5 to 1. The growth of the underdeveloped countries, as suggested in Table II-8 is a matter of speculation.

TABLE II-9 Metals Consumption per Capita in Selected Industrial Countries (U.N. and A.B.M.S.).

Country	G.N.P. $ per capita (1953 $'s)		Metal Consumption, lbs/yr/capita									
			Iron Ore (tons Fe)		Copper		Zinc		Lead		Aluminum	
	'50	'57	'50	'57	'50	'57	'50	'57	'50	'57	'50	'57
U.S. - new	1,740	1,970	792	861	18.1	15.0	12.7	11.0	11.7	8.3	11.8	20.9
U.S. - total					27.4	19.8	12.7	11.0	16.3	13.3	12.8	21.8
U.K. - new	685	810	388	563	14.9	22.0	10.5	10.1	7.2	7.3	8.0	9.4
U.K. - total					23.5	27.8	14.7	13.8	14.6	15.1	--	--
W. Germany - new	393	630	400	726	8.5	17.4	5.5	9.9	4.8	8.0	2.3	8.9
France - new	650	845	374	545	6.1	9.9	5.0	7.0	3.2	6.2	2.4	7.6
Belgium - new	650	780	851	1,240	14.7	17.0	15.3	24.2	12.8	14.3	1.4	6.7
Sweden - new	914	1,080	238	422	15.7	15.7	6.3	7.2	9.0	8.9	3.9	8.8
Japan - new	139	218	56	157	1.9	4.3	1.4	3.4	.6	2.1	.5	1.7

P. Moussa suggests that an annual investment of $30 billion would provide enough capital to support an annual 4 to 5% per year growth in the per capita income of 1,900,000,000 persons[22]. This estimate includes the Soviet sphere countries and for the time being probably represents the maximum that is feasible. To translate this investment rate into the additional metals consumption needed for capital goods purchased as a part of the program requires some additional calculations, and these are presented in Appendix II together with an assessment of the capital-output ratios upon which these figures are developed.

The question of anticipating substitutes involves even greater intangibles. It is a fair generalisation to say that the advantages that metals have over other materials lie in two categories. First is the quality of ductibility combined with high strength, and second is the specific metallic properties such as the conductivity of heat and electricity, magnetism and chemical characteristics.

As yet no non-metallic material has been developed that approaches the better metallic materials in terms of combined strength and ductibility;[*]

[*]The physical properties of materials are usually described on a dimensional rather than a weight basis. The low density of plastics can be put to advantage in certain circumstances.

these properties of metals are, moreover, retained over a wide range of temperatures. Alloying is often needed to obtain the best properties, but this requirement is not costly. Thus ordinary steel selling at a cost of 5¢ per pound has a tensile strenth many times that of the best plastic which costs many times as much. However, lead and zinc and alloys, and aluminum and alloys to a lesser extent, do not have the strength of steel and in some cases are almost matched by plastics.

There is likely to be little competition with metals in their use as conductors of heat and electricity, since non-metals do not have these properties. Non-metallics, specifically metal oxides have, however, made small inroads into the use of metals for magnets. Metals are very vulnerable to substitution when they are used as chemicals, either in the metallic state or as a metal compound; this classification includes metals and compounds as protective coatings. Thus lead as a protective coating for electric cables has been replaced by plastics, as has lead in paints by titanium dioxide. Plastic coatings may, in time, replace zinc, aluminum and tin as protective coatings on steel. The use of lead tetraethyl as an additive to gasoline has not been replaced in spite of exhaustive research in the field, but there is little doubt that a substitute will be developed eventually.

Metals are, in fact, least vulnerable to replacement where their use depends upon uniquely metallic properties. Thus toughness, electrochemical properties, and the conduction of heat and electricity are properties in which metals have, as yet, broad advantages over non-metals. Metal alloys, such as die-casting alloys and alloys of

lead and zinc in general, that have inferior physical properties, often face severe competition from plastics and it is only the cheaper cost of the metal alloys that assures their continued use. Metals in metallic compounds also face severe competition from non-metallic compounds, for in this case the latter are often cheaper than compounds containing the common metals. If, once again, one might be permitted a generalisation, metals make cheap materials of construction but costly chemical reagents.

The possibility of substitution of metal for metal also presents many problems. The usual substitutions suggested are aluminum for zinc, copper or steel. At present prices, zinc at 14¢ per pound and aluminum 28¢ per pound, aluminum is cheaper than zinc on a volume for volume basis and thus a continued substitution of aluminum for zinc in die-casting alloys can be expected.* Aluminum coated steel as a substitute for electroplated galvanised steel cannot be expected for a while since the latter uses much less metal than does a dip process using aluminum; electroplating of an aluminum coating is not possible. Aluminum sheets have replaced galvanised sheets, but the latter has a price advantage.

Aluminum is likely to replace copper where the conductivity of heat or electricity is the characteristic sought. Replacement of copper in high-tension transmission cables by steel-cored aluminum is almost complete. The replacement of copper by aluminum in the electrical field will not be complete for some time to come, because soldering of copper is much easier than any convenient comparable joining method for aluminum, and copper conductors are much less bulky for the same electrical carrying power. Thus

*This conclusion only applies to cases where strength is unimportant since the zinc alloys are significantly stronger than the aluminum alloys.

aluminum probably will not replace copper in electrical work that involves many joins in the conductor nor where compactness is required, as in motors.

Aluminum will probably replace steel in those applications where it is not so much the strength of the material but ease in construction~~, rigidity,~~ and durability that count. Transportation equipment is an outstanding possibility in this respect. In many cases steel will not be replaced for some time to come due to its cheapness and its strength. Where weight is a disadvantage and strength not needed, however, aluminum will continue to make inroads into fields where steel previously was used exclusively.

It seems then, quite possible that the traditional metals, copper, lead and zinc will be replaced to some degree by plastics and by aluminum. There will, as noted above, be limitations to the process of substitution. Steel may also be replaced to some degree but it will be a number of years before this substitution begins to show an effect on steel consumption.

Nickel, on the other hand, is rarely used alone, its biggest use being in high nickel content alloys. Replacement in these fields is always difficult to foresee for new alloys may, at any time, be introduced that would require much less, or even negligible, quantities of nickel. In stainless steels the position of nickel appears to be fairly secure, although the substitution of manganese stainless steels is gaining ground. In a number of cases stainless steel and aluminum are in competition. These two metals are in the same price range and though the former is much stronger, the latter is considerably lighter. Nickel in high temperature alloys is another important

application. There appears to be no important potential substitute in the same price range as nickel at present.

Possible substitutes for aluminum include titanium, magnesium and plastics. The two former are considerably more expensive than aluminum and, in general, plastics do not have such favourable strength properties. There are, however, fields in which aluminum is vulnerable to advances in any one of these three materials.

Substitution for iron and steel, except for those already mentioned, appear to be unlikely except on a relatively small scale. Alloy additions to steel provide such a multiplicity of properties which, in addition to the moderate cost, make the scope for substitution rather limited.

As a basis for further development and discussion in Chapters III and IV, the rates of growth of metals consumption suggested have been tabulated in Tables II-10, II-11, II-12, II-13, II-14 and II-15.

It will be noticed that in a number of cases it has been assumed that technology will be at about the same degree of development in the United States, the United Kingdom and Canada. Some of the European countries will not be very far behind but, taking the area as a whole, it has been assumed that technology will be less developed than in the United States.

On the other hand, it has been assumed that the United States and the United Kingdom are the most mature economies while Western Europe and Canada are less so. Once again this classification of Western Europe must be regarded as a generalisation taking in all national groups.

Furthermore, in most cases, it appears that the Japanese economy will continue to progress at a rate of about 5% per year and that of Soviet Asia at 10% per year. The justification for this growth rate is that there is the requirement and the organisation suitable for such growth in each of these areas.

The selection of an annual output upon which to base the growth also presented some problem. In most cases the year 1955 was chosen, with suitable modification depending on activity in 1956, 1957 and 1958. In Western Europe and Japan, recovery after the war was not quite complete in 1955, but this situation has been taken into account in the selection of the base tonnage and of the annual increase rate.

In the tables that follow, forecasts have been made for the increase of metal consumption for a number of nations or groups of nations. This grouping has left out some nations that at present consume metals in significant quantities, and these are included in "Rest of World". Estimating the % annual increase in metals consumption for such a heterogeneous group is dangerous, but in most cases the figures used err on the side of high consumption in the belief that as time goes on, more and more nations will join this classification with the onset of rapid economic growth. Two other figures are presented in the tabulations, though not included in the totals. These represent attempts, in one case, to include metals imported as components of machinery and as items imported, though not classified separately. The second figure indicates the total metals consumption if a program of a maximum rate of annual investment were undertaken in the underdeveloped countries. The derivation of both of these sets

*

See page [illegible] Appendix I

of figures is described in detail in Appendix II.

TABLE II-10 Future Consumption of Iron Ore (tons of Fe).

Area	Base Tonnage	% growth/year over 25 years	Annual Consumption 1980
United States	70,000,000	2.0%	118,000,000
United Kingdom	13,000,000	2.0%	22,000,000
Western Europe (excl. U.K.)	42,000,000	3.0%	94,000,000
Canada	3,000,000	3.0%	7,000,000
Japan	5,000,000	5.0%	18,000,000
Eastern Europe (incl. U.S.S.R.)	47,000,000	3.5%	117,000,000
Soviet Asia	4,000,000	10.0%	45,000,000
Other Iron Producers	14,000,000	3.5%	35,000,000
Rest of World, crude steel imports	(13,000,000)		
Rest of World, machinery imports	(9,000,000)		
Rest of World, consumption based on an investment outlay (Appendix II)			(13,000,000)
Totals	198,000,000	134.0%	462,000,000

An annual increase of 2% per year was allowed for the more mature economies - the United States and the United Kingdom. Somewhat greater rates of growth were allowed for Canada and Western Europe (excl. United Kingdom) since it was felt that industrialisation would proceed in the case of the former, while for the latter the benefits of oil and gas discoveries both on the Continent and in North Africa would be felt as time went by. Moreover, the rationalisation of trade arrangements would show improved activity as would European exports to underdeveloped countries. These countries in Europe also have some ground to gain in raising their standards of living closer to that of the United States.

It is expected that growth in the Japanese economy will proceed at the present high rate, and with it, steel and iron ore consumption.

The rate of growth suggested for Eastern Europe and the U.S.S.R. will probably be attained, as will that in China, as a part of an enforced investment program.

The tonnages of iron ore needed in the underdeveloped countries is difficult to predict, due to statistical inadequacies as well as to uncertainties of a political nature. The base tonnage figure is that which can be collected from published data on pig iron output. Thus full allowance for imports has not been made. Some of the imported items are already accounted for in the United States, European and Soviet figures. However, estimates of the iron content of machinery imports and of a hypothetical investment outlay, see Appendix II, have been included. These figures, crude steel, machinery and investment outlay should thus not be included in the world total since these items are already taken into account.

The future consumption of copper according to country and area are presented in Table II-11.

TABLE II-11 Future Consumption of Copper (New).

Area	Base Tonnage	% growth/year over 25 years	Annual Consumption 1980
United States	1,280,000	1.5%	1,920,000
United Kingdom	450,000	1.5%	675,000
Western Europe (excl. U.K.)	824,000	2.5%	1,630,000
Canada	110,000	2.5%	220,000
Eastern Europe (incl. U.S.S.R.)	520,000	3.5%	1,300,000
Soviet Asia	12,000	10.0%	135,000
Japan	125,000	5.0%	450,000
Rest of World	250,000	5.0%	900,000
Rest of World, pro-rated on steel and machinery imports	(280,000)		
Rest of World, consumption based on investment outlay			(234,000)
Totals	3,571,000	106.0%	7,356,000

A rate of increase of 1.5% per year is suggested for copper for the mature economies. This figure reflects a degree of substitution in the use of copper and the introduction, progressively, of methods to economise in the use of metals and employing more advanced techniques of manufacturing.

Rates of growth in consumption higher than in the United States are suggested for Canada and Western Europe (excl. United Kingdom), for it is felt that higher living standards will be sought by these countries. The European recovery was not quite complete in 1955 and this is, perhaps, another justification for selecting higher growth rates for these areas as compared with the United Kingdom and the United States. Furthermore, the substitution of other metals for copper will not be quite so rapid in Western Europe as it is in the United States until the decade 1970-80. It is noteworthy that the per capita consumption of copper was as high in Western Europe as it was in the United States in 1957, see Table II-9. This high consumption in Western Europe is ascribed to machinery exports by these countries.

The rates of copper consumption increase suggested for Eastern Europe (incl. U.S.S.R.),for Soviet Asia and for Japan are justified on the grounds that these countries will continue to work towards increased living standards. This trend will be reflected in the use of more power in industry which, in turn, will increase the consumption of copper.

The figures for the increase in copper consumption in the underdeveloped countries probably represent a maximum figure. Various methods of computing these predicted figures are presented in the table and explained in detail in Appendix II.

The future consumption of lead has been treated similarly to that of copper and the figures obtained are set out in Table II-12.

TABLE II-12 Future Consumption of Lead (New).

Area	Base Tonnage	% growth/year over 25 years	1980 Tonnage
United States	700,000	1%	930,000
United Kingdom	200,000	1%	266,000
Western Europe (excl. U.K.)	600,000	2%	1,000,000
Canada	50,000	1%	67,000
Eastern Europe (incl. U.S.S.R.)	350,000	3%	780,000
Soviet Asia	20,000	10%	224,000
Japan	50,000	5%	180,000
Rest of World	130,000	5%	470,000
Rest of World, pro-rated on steel and machinery imports	(150,000)		
Rest of World, consumption based on investment outlay (Appendix II)			(123,000)
Totals	2,100,000	86.5%	3,917,000

An annual increase in lead consumption of 1% per year was estimated for the mature economies; substitution will have a significant effect throughout the period. Canada has been classified with the United States and the United Kingdom in this case, since Canadian technical development has kept closely in step with these countries.

Substitution will not be so severe in Western Europe (excl. United Kingdom) as in the United States, the United Kingdom and Canada due to the lower degree of development of the plastics industry. However, it is felt that in the decade 1970 to 1980 substitution will become more important in Europe and the lead consumption-tonnage may not actually exceed that in the United States as indicated by the table.

Lead consumption in the less mature economies, included under the category "Rest of World", will probably not slacken in

growth as it will in the Western countries due to the present lower degree of development in the plastics industry. It should be noted that the split between Eastern Europe (incl. U.S.S.R.) and Soviet Asia has to be somewhat arbitrary, but was needed since the former represents a much more highly developed economy.

Estimates of the future consumption of new zinc, consumed in metallic form, are contained in Table II-13.

TABLE II-13 Future Consumption of Zinc (New).

Area	Base Tonnage	% growth/year over 25 years	1980 Tonnage
United States	900,000	1.5%	1,350,000
United Kingdom	250,000	1.5%	375,000
Western Europe (excl. U.K.)	600,000	2.0%	1,000,000
Eastern Europe (incl. U.S.S.R.)	450,000	3.0%	670,000
Canada	70,000	1.5%	105,000
Soviet Asia	40,000	10.0%	500,000
Japan	120,000	5.0%	430,000
Rest of World	190,000	5.0%	670,000
Rest of World, pro-rated on steel and machinery imports	(200,000)		
Rest of World, consumption based on investment outlay (Appendix II)			(166,000)
Totals	2,620,000	94.5%	5,100,000

Although there are general similarities between the situations relating to lead and zinc, there are also some major differences. Thus a much larger proportion of the lead output comes from scrap than is the case for zinc (10-20%). The strength of zinc still probably lies in its expanding use in galvanising. About half of the zinc used in the United States is used in galvanising and the consumption of galvanised sheet appears to follow along with steel output. Galvanised metal is likely to be used in large quantities for the construction of temporary buildings.

Rather similar consumption patterns are suggested for lead

and zinc. Thus in the case of Canada, advanced technology places her with the mature economies rather than the more rapidly expanding economies of Western Europe, Eastern Europe and elsewhere.

Forecasting the future demand for both nickel and aluminum is more difficult than for the other metals, and thus a more detailed discussion has been attempted. Difficulties arise because the former metal is continually finding new uses in capital and defense goods, the consumption of which fluctuates widely, while the latter is being substituted for other metals very extensively. Taking the case of nickel first, increases of 2.8% and 3.5% (5.0% for non-defense consumption) have been predicted by the Paley and the Gordon Reports respectively. In recent years an annual increase in consumption of 4 to 5% has taken place and an increment of 25.000.000 lbs per year has been predicted on a number of occasions[24]. In the ten years 1948-57 there has been the understandable increase in the consumption in the war-damaged countries such as Germany, France, Japan, but there has also been a 50% increase in consumption in Britain and a doubling of consumption in Sweden. In the United States itself consumption has been increasing at the rate of about 3.5% per year. Consumption of nickel in the manufacture of stainless steel and high temperature alloys has shown notable growth in the past decade and there is little reason to doubt that such a trend will persist, as more severe service is required in certain applications. It would be satisfying in this connection to be able to postulate a trend towards more durable materials with the objective of offsetting high maintenance expenses by relatively lower capital expenses. However, such a hypothesis cannot be supported since the corroborating evidence is not available

at this stage, and we must be content with the assertion that more severe operating conditions for equipment are being demanded continually; certainly in a number of cases progress is curtailed by a lack of adequate materials of construction[25]. Nickel, in fact, is used widely for capital goods and, except for its application in plating, it does not enter extensively into consumer products.

The consumption of nickel thus tends to be concentrated in the industrialised countries and will continue to be so for some time to come. However, nickel is used in those fields where it is anticipated that production will grow most rapidly, viz. aircraft, plastics, power generation, chemicals and similar fields[26].

TABLE II-14 Future Consumption of Nickel.

Area	Base Tonnage	% growth/year over 25 years	1980 Tonnage
United States	110,000	3.5%	258,000
United Kingdom	23,000	3.5%	54,000
Western Europe (excl. U.K.)	35,000	5.0%	119,000
Eastern Europe (incl. U.S.S.R.)	50,000	3.5%	118,000
Canada	5,000	3.5%	12,000
Soviet Asia	--	--	--
Japan	3,000	5.0%	10,000
Rest of World	1,500	3.5%	4,000
Rest of World, pro-rated on steel and machinery imports	(25,000)		
Rest of World, consumption based on investment outlay (Appendix II)			(21,000)
Totals	227,500	153.0%	575,000

The annual growth increments selected for the nickel consumption of each area are presented in Table II-14. It is believed that in the United States and other countries of a similar level of development, the rate of consumption growth that has prevailed for more than the last decade will persist. Thus in the United States,

the U.S.S.R. and Britain, where highly developed aircraft industries are established and where, except for the U.S.S.R., the chemical industry has attained some magnitude, growth at 3.5% per year is assumed. For the Western European countries, excluding the United Kingdom, and Japan consumption of nickel has lagged somewhat and a higher rate of growth is suggested. The ratios between the consumption of each of the six metals in the United States and other of the main consuming centres of the world is interesting.

TABLE II-15 Relative Consumption of Base Metals in Various Industrial Areas of the World (1955).

Area	Ratio for Each Metal for Each Area					
	Iron Ore	Copper	Lead	Zinc	Nickel	Aluminum
United States	1.0	1.0	1.0	1.0	1.0	1.0
Western Europe (excl. U.K.)	.715	.695	.856	.667	.320	.343
Eastern Europe (incl. U.S.S.R.)	.606	.278	.500	.500	.455	.316
United Kingdom	.18	.283	.285	.278	.209	.172

This comparison is contained in Table II-15 and shows that though rather similar ratios are obtained for iron ore, copper, lead and zinc, for nickel and aluminum the United States is a much more important consumer. The relative consumption of nickel and aluminum in Eastern Europe including the U.S.S.R. is perhaps closest to that of the United States, although the United Kingdom is significantly in advance of Western Europe. It is believed that Western Europe will gradually become more deeply involved in the manufacture of high performance heat engines and of chemical plants and a rapid growth of nickel consumption is to be expected. A similar trend, starting from a somewhat lower consumption level is anticipated for Japan.

Prediction of future demand for aluminum is similarly difficult.

There is little doubt that aluminum is well established in its present uses: the question is to what extent it will replace other metals and materials in the next two decades. The industry confidently expects continued replacement as well as expansion in fields that it already dominates[27]. This attitude must have been reinforced by the United States consumption figures for 1959 which show a total of almost 2,200,000 tons of new metal. In some cases the additional tonnage gained will be relatively slight, though continuously growing, elsewhere the ultimate growth potential could be enormous. Thus the actual remaining tonnage of copper used in electrical equipment that could now be replaced by aluminum may be relatively low; it is generally believed that copper will still be used for winding electric motors, generators and transformers and other equipment where compactness is of great importance. Elsewhere the difficulty in making connections with aluminum wire precludes it from some uses. For the time being it appears that the principal application for aluminum in electrical products will be in transmission cables. In 1958 approximately 170,000 tons of aluminum wire was used in the United States for electrical applications[28]. During the same period about 400,000 tons of copper was used for all applications in the field of which approximately 120,000 tons was used for transmission work[29]. However, since the electric power generated in the United States doubles about every 10 years, the consumption of metal for electrical transmission on a world-wide basis soon reaches very large proportions[30].

One reason for the very high consumption of aluminum in the United States during 1959 was the progressively greater quantities taken by the automobile industry. In 1960 General Motors expects to

use about 52 lbs per car and in 1961 Chrysler 71 lbs per car, while all three of the large manufacturers have contracts with primary aluminum producers to obtain hot metal directly[31]. The quantity of hot metal so obtained is in addition to substantial quantities of secondary aluminum also consumed. To the present almost all the aluminum purchased by the automobile industry is used in castings. The use of wrought products for wiring, for body-work and for radiator tubes is also anticipated in time.

Substantial quantities of aluminum are used in construction, the largest single use,and in packaging. In both these applications the ultimate scope could be very large. However, at present aluminum is at a very definite price disadvantage as compared with steel,and only where the lightness of aluminum allows structural or operating economies, can substitution be justified. It has been estimated that on a volume basis (this applies to uses where strength is not needed) aluminum is twice as costly as steel[32].

Viewing the overall picture,it appears that if the present trends in the United States continue and if they are reinforced to any degree by similar movements abroad, very large increases in aluminum consumption will take place. Reference to Table II-15 shows how significant such a factor could be. During 1957 the per capita consumption of copper, lead and zinc was not greatly different in the industrialised European countries from that in the United States, while the consumption of aluminum in Western Europe was less than half that in the United States.

TABLE II-16 Future Consumption of Aluminum.

Area	Base Tonnage	% growth/year over 25 years	1980 Tonnage
United States	1,750,000	5.0%	6,650,000
United Kingdom	300,000	6.0%	1,290,000
Western Europe (excl. U.K.)	600,000	7.5%	3,600,000
Eastern Europe (incl. U.S.S.R.)	550,000	7.5%	3,300,000
Canada	90,000	5.0%	340,000
Soviet Asia	100,000*	10.0%	680,000
Japan	55,000	7.5%	330,000
Rest of World	60,000	7.5%	360,000
Rest of World, pro-rated on steel and machinery imports	(360,000)		
Rest of World, consumption based on investment outlay (Appendix II)			(290,000)
Totals	3,460,000	6.5%	16,550,000

*1960 was taken as the base year[33]; 60,000 tons domestic production plus 40,000 tons imports

The Paley Report anticipates a total increase of 5.15 times on a world-wide basis, while the Gordon Report anticipates a 8.56 times expansion. The figures presented in Table II-16 are compiled by using a selected compound growth rate for each area. Somewhat lower growth rates are predicted for the United States and Canada than for the rest of the world. In total the prediction is on the conservative side when compared with the Gordon Report figures. This lower rate of growth is suggested on the basis of the contention that towards the end of the 25 year period under consideration the annual increase in the consumption of aluminum will have begun to taper off.

In this chapter the consumption of the six metals considered has been estimated over a twenty-five year period to 1980. The chapter that follows will be concerned with the supply of these metals.

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Note: A sample calculation of the projected copper production in Japan in 1975 goes as follows:

Accounting for a population increase to 111 millions from 83.2 millions, an increase in working population of from 50 to 72 millions, with no change in hours worked, but with an increase in labour productivity of 121%, a 3.2 fold increase in Gross National Product was projected.

The increase in new copper consumption in the United States of this period was 43% and thus the total increase in Japan would be

$$(43 + 10)\ 2.2 = 117\%$$

This projected increase was rounded off to 110% in the Paley estimates.

Combining estimated population increase, work force change, productivity change for each country or group of countries, the consumption of each metal was calculated as in Table II-5. It should be noted that this method of calculation was always applied rigidly and that there was considerable rounding-off at the discretion of the staff.

Chapter III

This chapter deals with the world supply of metals against which any production from the Canadian North will have to compete. In Chapter II an attempt was made to arrive at single estimates of the future world consumption of iron ore, copper, lead, zinc, nickel and aluminum. These future consumption demands will have to be met by a supply of new and secondary metals.

The procedure, established in the previous chapter, of assuming that Canadian metal output will have to face world markets, is continued here as is the assumption that the real price of the metals will not change over the twenty-five year period specifically considered. An examination of this second assumption is postponed until Chapter IV. It is appropriate, however, to indicate here that high metal prices cause an effective increase in ore reserves, since deposits that previously were uneconomic become economic and bring about a considerable intensification of exploration activity. At the same time the use of metals, provided there are no close substitutes, cannot be too sensitive to price since the value of the metal content of many manufactured products is very low.*

Under these circumstances shortages and surpluses of a particular metal will be felt promptly throughout the world and, as an extension of this premise, the demand and supply of the Soviet-bloc countries must also be included so far as is possible. Further-

*However, the elasticity of substitution between metals in certain cases is very high as was indicated in Chapter II. It does not seem likely that differential prices of metals will, in general, change too greatly except for a new metal establishing itself, or for drastic technological change, since prices must now be a reflection of long-run costs in most cases.

more, attention will be directed to the wealth of ore reserves of a particular area rather than to its present output. Generally speaking, high output is derived from large reserves; there are some exceptions to this rule, as for instance when an extensive deposit is close to exhaustion, but even these cases seem to be relatively rare. A more usual situation is that a large low-grade deposit remains after depletion of the high-grade ore and highly mechanised techniques are employed to obtain low costs through very large outputs. As is to be expected, large reserves do not necessarily bring about large outputs and in most cases the grade of the ore is a key factor for, all things being equal, small differences in the metal content of the ore result in very large differences in profits.

The first topic to be discussed in this chapter is thus the world reserves of iron ore, copper, zinc, lead, nickel and aluminum. The most recent published figures will be used directly. Some evaluation of the reserve statistics will be attempted. A later section of the chapter will be devoted to a consideration of the rôle that secondary (scrap) metals play in the world supply of metals.

The reserves of ore listed below represent tonnages of minerals that can be mined at current metal prices. There is, thus, likely to be a change in world reserves from year to year depending upon current metal prices.

Recent figures for the world reserves of iron ore appear in Table III-1[1]. The direct shipping ores contain in excess of 50% iron, while the ores needing beneficiation run between 25 and 50% iron. These grades are close to those of the ores mined regularly.

TABLE III-1 World Iron Ore Reserves (January 1959). (Millions of tons Fe.)

Country	Reserves	Overall Grade % Fe
United States	20,086	31.4
Canada	5,327	39.0
Brazil	20,925	40.0
Cuba	1,200	40.0
Venezuela	1,430	65.0
France	2,861	34.3
Germany	455	30.1
Norway	506	34.0
Sweden	1,513	63.0
United Kingdom	1,215	26.4
U.S.S.R.	18,928	31.6
Guinea	1,550	62.0
Liberia	600	60.0
China	3,576	32.0
India	37,940	35.7
Japan	27	42.1
Philippines	641	48.2
Total (incl. those not separately listed)	126,056	

A recent estimate of the world's copper ore reserves was prepared by the United States Bureau of Mines. The figures published are presented in Table III-2 and state the situation as of January 1958. The estimates were based on ore that was of the minimum grade, or higher than that mined at present[2].

TABLE III-2 World Copper Ore Reserves (January 1958).
(Millions of short tons of contained copper.)

Region	Reserves
South America	
Chile	46
Peru	12.5
North America	
United States	32.5
Canada	7.0
Mexico	.75
Africa	
Northern Rhodesia	24.5
Belgian Congo	20.0
Union of S. Africa and S.W. Africa	1.1
Oceania	
Australia	1.0
Asia and Europe	
Soviet Bloc	16.0
Yugoslavia	1.2
Turkey	.5
Cyprus	.2
Philippines	1.0
Other Countries (Cuba, Bolivia, Finland, Norway, Spain, Sweden, India, Japan)	6.0 (ore)
	170,000,000 tons copper metal

These figures refer to measured ore only and appear to be very reliable. Possible discrepancies lie in the Australian and the Soviet Bloc figures. The total reserves for Australia are listed as 1,000,000 tons of copper and these are divided between Mount Isa, 670,000 tons, Mount Lyell, 340,000 tons and Mount Morgan, 150,000 tons according to the 1958 Yearbook of the American Bureau of Metal Statistics[3]. However, recently Mount Isa constructed a new refinery

and before completion increased its capacity from 40,000 to 60,000* tons per year suggesting that there must be considerably more than ten years of ore in sight[5]. The estimates of Russian ore reserves may also be on the slender side, since the U.S.S.R. plans to increase its annual output to 800,000 tons of copper per year by 1965[6].

World ore reserve figures have also been prepared for lead and zinc by the United States Bureau of Mines[7]. These estimates were based on current costs and prices prevailing January 1, 1957. Once again measured ore reserves are listed although estimates of inferred amounts are also included[8]. It is felt that these estimates, Tables III-3 and III-4, are very reliable.

TABLE III-3 World Reserves of Lead (January 1957).
(Millions of tons of lead.)

Region	Reserve	Inferred Ore (additional)
North America		
Canada	8,033,000	8,000,000
United States	2,910,000	5,000,000
Mexico	3,525,000	3,000,000
Other	150,000	
South America		
(Argentina, Bolivia, Peru, Chile)	2,500,000	
Europe		
Western	9,100,000	
Eastern	4,600,000	
Africa		
(Algeria, Belgian Congo, Morocco, N. Rhodesia, S.W. Africa, Tunisia)	3,500,000	
Asia		
(Burma, China, India, Iran, Japan)	2,000,000	
Oceania		
Australia	12,500,000	
	48,818,000 tons of lead	

*Ultimately to go to 100,000 tons per year[4].

TABLE III-4 World Reserves of Zinc (Janauary 1957).
(Short tons of zinc metal.)

Region	Reserve	Inferred Ore (additional)
North America		
Canada	16,691,000	60-100,000,000
United States	13,485,000	
Mexico	6,650,000	
Other	175,000	
South America		
(Argentina, Bolivia, Peru, Chile)	6,000,000	
Europe		
Western	11,000,000	
Eastern	11,000,000	
Africa		
(Algeria, Belgian Congo, Morocco, N. Rhodesia, S.W. Africa, Tunisia)	4,000,000	
Asia		
(Burma, China, India, Iran, Japan)	4,500,000	
Oceania		
Australia	11,000,000	
	84,501,000 tons of zinc	

So far as is known no very recent compilation of the world nickel ore reserves has been published. However, as the statistics in Table III-5 show, the lack of recent data does not present any difficulties in an evaluation of the situation due to the extent of reserves[9]. The table differs in form from those used for lead, zinc and copper since both developed and undeveloped reserves are listed as well as reserves according to the type of ore. Generally the undeveloped ore is not of sufficiently high grade to justify immediate exploitation. To the present, sulphide ores have been, on the whole, more amenable to treatment, although Cuban and New Caledonian ores have also been developed where extra high-grade zones appear, or, in the case of the former, where strategic reasons have accelerated development. As a generalisation, non-sulphide ores cost about twice as much to process as sulphide ores and since sulphide ores usually run 1 to 2% nickel, while the Cuban ores contain 1.5% nickel

and New Caledonian ores up to 3.0% nickel, the two latter are only just competitive. Most of the other ore reserves listed in Table III-5 are of less than 1.5% nickel.

TABLE III-5 World Reserves of Nickel Ore (1955).
(Thousand short tons of contained nickel.)

Country	Sulphide Ore Developed	Sulphide Ore Undeveloped	Nickeliferous Iron Ore Developed	Nickeliferous Iron Ore Undeveloped	Silicate Ore Developed	Silicate Ore Undeveloped
North America						
Canada	4,822	500	--	--	--	--
United States	--	140	--	153	257	--
S. + Central America						
Cuba	--	--	1,413	16,457	--	--
Brazil	--	--	--	--	--	2-400
Venezuela	--	--	--	--	--	4-875
Asia and Europe						
Celebes + Borneo	--	--	--	4-7,000	--	80
Philippines	--	--	--	--	--	4,500
Japan	--	--	--	315	--	--
Greece	--	--	--	--	12.5	50-100
Oceania						
New Caledonia	--	--	--	--	464-514	16,000
Totals	4,822	640	1,413	19,425	759.5	21,630

Since 1955 one or two discoveries of sulphide nickel ores have been of significance. Thus the Mystery Lake deposits of the International Nickel Company are being developed and are to produce something of the order of 50,000 tons per year of nickel suggesting an addition of 1,000,000 tons of nickel to the Canadian developed reserves is justified. Year by year both International Nickel and Falconbridge, who together hold a very large proportion of the Canadian Nickel reserves in their Ontario properties, manage to develop as much ore as they consume implying that the reserve figures published are probably backed by significant tonnages of inferred ore. Nickel discoveries in Ungava are also considerable but have not been developed

to any degree, while the Emperor mine in Southern Rhodesia, owned by Rio Tinto, will probably be brought into operation in the next decade. Both these deposits are of sulphide minerals.

Two further nickel producers have been omitted from Table III-5 due to a lack of complete information. The Soviet Bloc is said to have reserves of 1,300,000 tons of nickel metal in ores of all three varieties[10]. Certainly the Russians are extremely active in their efforts to develop processes for the treatment of nickel ores[11]. A second producer of nickel is the Union of South Africa. The nickel output is a by-product of the platinum production from ores of the Marensky Reef[12]. Nickel production in the U.S.S.R. currently runs at about 70,000 tons per year and that of South Africa at 2,500 tons per year[13].

The estimates for the world reserves of bauxite are also somewhat out of date. Table III-6 shows the bauxite reserves as of October 1950[14]. Since the date of this estimate a number of very large deposits have been discovered in Northern Queensland (1.0 billion tons), in French Guinea (1.6 billion tons) and in the Cameroun (.5 billion tons)[15,16].

Bauxite is generally regarded as the principal ore for aluminum but, in fact, the Russians have developed processes by which a number of aluminum bearing minerals can be exploited[17]. Thus nephelite, sillimanite, alunite and anorthite* are all used as sources of aluminum and subsequently aluminum metal. The cost of such additional

*These are some examples from a long list of minerals that might be used. The chemical composition of these four are, respectively, $Na_2O.Al_2O_3.2SiO_2$, $Al_2O_3.SiO_2$, $K_2O.3Al_2O_3.4SO_3.6H_2O$ and $CaO.Al_2O_3.2SiO_2$.

processing adds substantially to the cost of the metal. Recently China has developed about 1 billion tons of bauxite reserves of various grades[18].

TABLE III-6 World Reserves of Bauxite (1950).
(Millions of tons.)

Region	Reserves
North America	
United States	44.5
South and Central America	
Brazil	210.0
British Guiana	71.5
Jamaica	352.0
Surinam	55.0
Haiti	25.8
	714.3
Europe and Asia	
India and Pakistan	28.0
Malaya	10.6
Yugoslavia	116.0
France	66.0
Greece	66.0
Indonesia	28.4
China	55.0
U.S.S.R.	33.0
Hungary	275.0
Rumania	22.0
Africa	
Gold Coast	262.0
Oceania	
Australia	23.1
	1,765.0 tons

The information upon which each of these estimates is based is derived principally from private companies engaged either in mining or in mineral exploration activities. The government geological surveys* rarely are able to carry out a detailed quantitative assessment of ore reserves and usually have to content themselves with reconnaissance surveys and with the collection and compilation of the information made available by mining companies, prospectors

*This term covers all government organisations that concern themselves with mineral resources and the mining industry.

and others. Of these sources of information, only the data collected by mining companies are suitable for the estimation of proven or measured reserves.

Unfortunately mining companies do not always make available to the public information on their ore reserves. They may not even have attempted to find for themselves their ultimate reserves if they have sufficient for 20 to 30 years of operation at current output rates. The development of ore reserves is likely to be a business decision rather than an attempt to contribute to a knowledge of ultimate ore reserves. An outcome of this situation is the phenomenon of a mine producing steadily from an ore reserve for years without the company indicating any depletion in these reserves. This effect is due, in part, to the much greater effectiveness with which reserves can be assessed once extensive workings have been established. Thus the reserves of the International Nickel Company in tons of metal have climbed each year even though these reserves have been mined steadily at an increasing rate.*

Furthermore, although the reports of mining companies made to government agencies provide the most reliable information available, they are to some degree incomplete. Unfortunately, the larger the deposit and the more significant its contribution might be to total world reserves, the less the incentive to carry out a complete assessment of ultimate reserves. In this respect S.G. Lasky noted: "Traditionally reserve estimates for porphyry copper deposits have been kept equal to 25 to 30 years production"[19].

*The "life" of the Company's Ontario ore reserves have fallen from over 100 years in the decade 1920-1929 to about 16 years in 1957 according to Company annual reports.

In an attempt to overcome these deficiencies in reserve estimates, S.G. Lasky of the United States Department of the Interior has suggested that a relationship, stated as follows, holds for many types of ore bodies:

$$\text{Grade of ore} = K_1 - K_2 \log.\ \text{tonnage} \quad \ldots\ldots\ldots\ldots(1)$$

In this equation K_1 and K_2 are constants that are determined empirically. This function is of somewhat limited application, though it does represent an attempt to estimate the extent of an ore deposit without the use of drill-hole exploration. It has been found that the relationship holds for a number of the porphyry copper deposits in the United States, for Falconbridge's nickel-copper mine in Ontario and for Alaska-Juneau gold mine[20]. For a "typical" large porphyry copper deposit the parameters have been calculated to yield a final relationship as follows:

$$\text{Grade of ore} = 12.9 - 1.4 \log.\ \text{tonnage} \quad \ldots\ldots\ldots(2)$$

This equation must be used with care since, if an exceptionally low overall grade is selected, rock containing no metal is included in the total tonnage.* An approximate calculation to show additional tonnages of metal that might be obtained if prices were increased sufficiently to justify the mining lower grade ores has been made and is included in Appendix III.

It is evident that to get an estimate of the ultimate reserves of metal it is necessary to go beyond the measured reserves listed in Tables III-1, III-2, III-3, III-4, III-5 and III-6. For lead and zinc, and nickel, if one includes undeveloped ore, some indication

*The "grade of ore" is taken to be the weighted overall grade for the entire tonnage mined.

of inferred ore reserves is given though in most cases these estimates are limited in coverage. The Paley Report attempted some assessment of the ultimate reserves of copper in the world at various grades[21]. This diagram, based on extrapolations of information supplied by mining companies, is reproduced in Figure III-1. Estimates of total world reserves of other metals in the Paley Report have been superseded by the information already presented.

A further attempt along these lines, probably an outcome of his work on correlating grade with tonnage in developed mines, has been made by S.G. Lasky. His approach implies that the output from a mine, a mining district or a series of districts tends to follow a pattern of rapidly increasing output, sustained output and finally falling output. He has fitted the annual output of a number of mineral products in the United States to a Pearl-Reed type of growth curve. Thus past production statistics for bituminous coal, copper, lead, zinc and aluminum have been used to establish relationships that should allow an estimate of future production and thus provide by summation a measure of ultimate output and present reserves. This procedure, if satisfactory, could be applied to each prominent mining area in the world and an estimate of the ultimate output, in total could be derived. However, the published account of this work[22,23] does not give an explanation for the variation in the mathematical procedures, see Appendix IV, and a complete evaluation is thus hampered. Lead output is shown to have passed a peak and to be declining steadily, while aluminum is climbing to a plateau. Copper and zinc (and coal) annual outputs have reached a plateau. The Pearl-Reed relationship, in a generalised form, can be expressed by the equation:

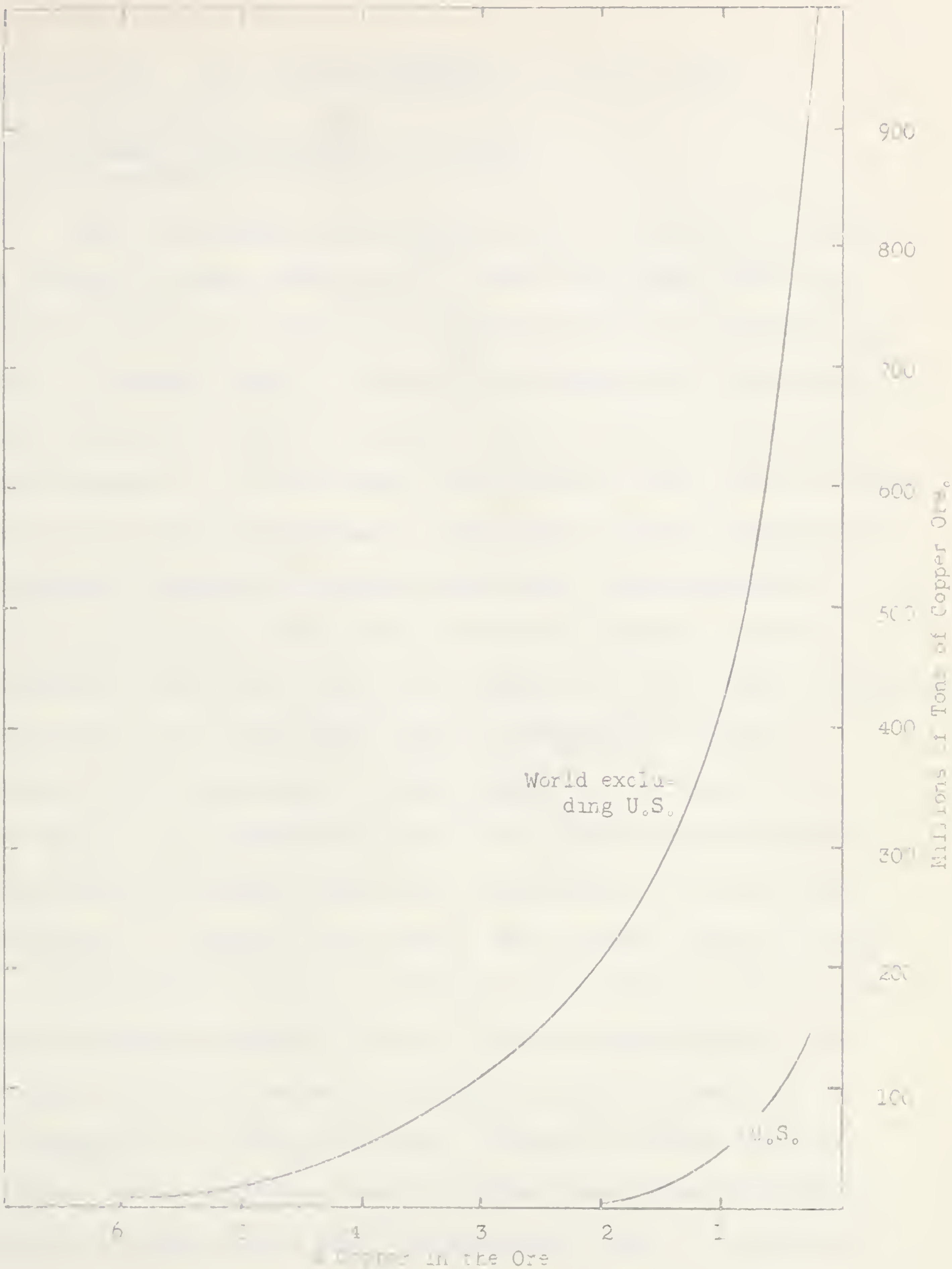

FIGURE [illegible] Grade of Copper Ore vs. Tonnage (21)

$$\frac{1}{y} = k + ab^{x} \quad \text{or} \quad y = \frac{k}{1 + 10^{a+bx}} \quad \ldots\ldots\ldots\ldots\ldots(3)$$

where y = population
x = date, time subsequent to a datum
k, a,b = constants

This relationship was originally used to describe the growth of a population under conditions of a fixed food supply. The total population rises to a plateau, see Figure II, while first differences comply to a normal curve. In one case, lead, Lasky uses the cumulative output (production added year by year) as his y term, in all other cases he appears to fit the annual output rates to the first difference curve (i.e. a normal curve) and to obtain his y value by integration, although the integration is never carried out. These procedures could be satisfactory, although one would have expected a greater similarity in the form of either the function or of the first differences. Beyond this, and a bias against using a mathematical function to describe a social phenomenon of some complexity, one wonders why there should be any similarity between the growth and stabilisation of population of living things and an accumulation of metal output. Furthermore, if, except in the case of lead, annual output is fitted and correlated with the first difference relationship, a plateau seems a rather unlikely outcome.* It may be that the annual output rate of copper, zinc and aluminum is presumed to grow and stabilise as the population of a country and thus y equals the output capacity developed. Such a hypothesis would, however, imply that population growth is the only factor that determines the output of a metal and

*The normal curve showing no tendency to form a plateau.

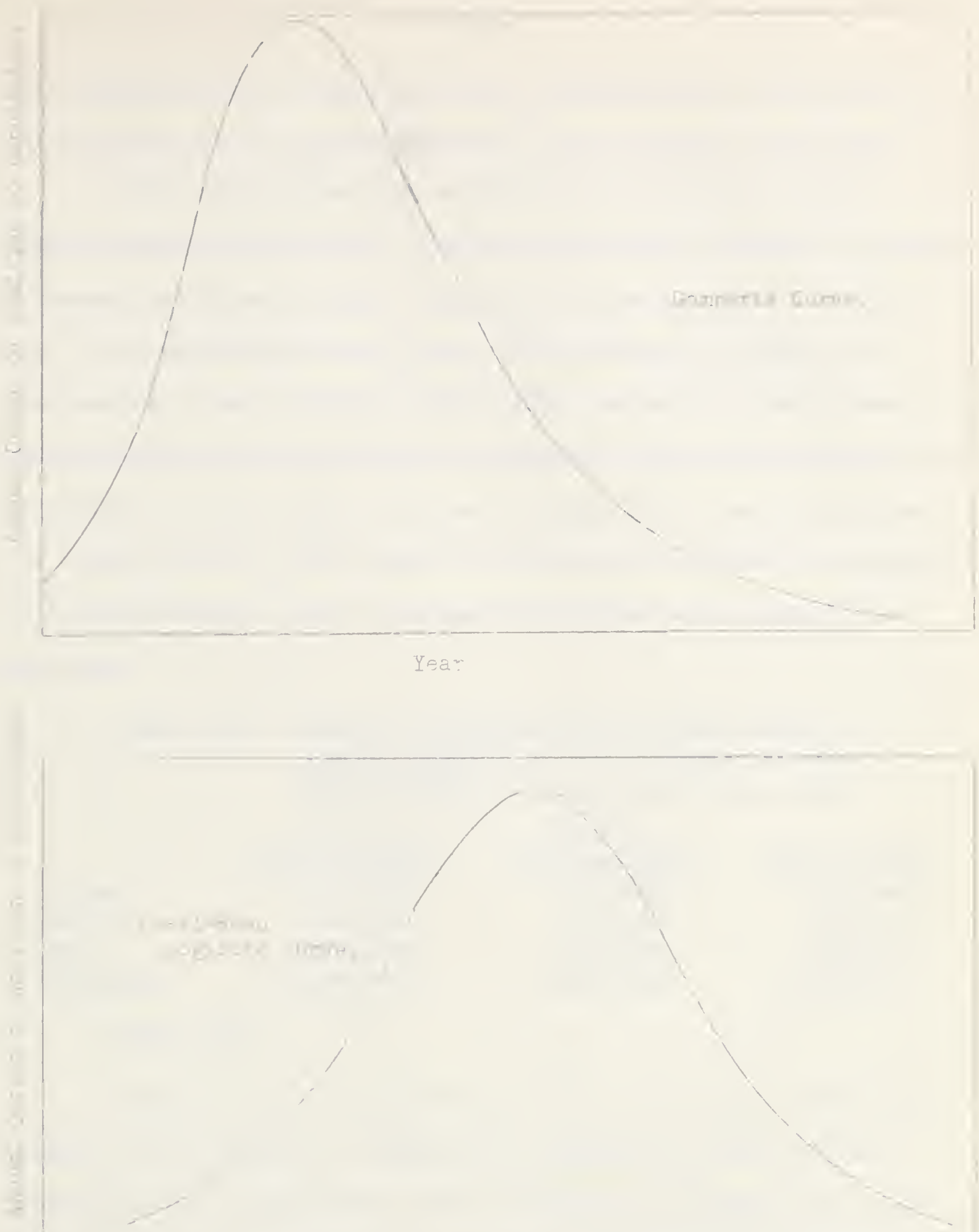

FIGURE III-2 First Differences for the Gompertz and Pearl-Reed Curves.

this supposition is obviously a gross simplification. Lasky does not speculate as to the significance of his equation parameters.

Table III-7 shows the estimated figures and the actual United States output figures for the decade 1949 to 1959. It provides a comparison between Lasky's forecasts in 1949 and 1954 for 1960 with the actual mine output in the United States in 1959. It is interesting to note that he consistently, during the last decade, underestimated the mine output of aluminum, copper and lead and over-estimated the mine output of zinc. He suggested an output plateau for copper and zinc. The output of lead did not diminish so rapidly as Lasky predicted, while aluminum output grew more quickly than expected.

TABLE III-7 Lasky's Estimates for the U.S. Output of Copper, Lead, Zinc and Aluminum in 1960. (Metal mined)

	1960 by 1949 estimate	1960 by 1954 estimate	1959 actual
Copper	750,000	800,000	979,000*
Lead	200,000	215,000	256,000
Zinc	660,000	680,000	425,000
Aluminum	1,200,000	1,525,000	1,953,000

*For 1958

Rather a lot of attention has been paid to this approach of Lasky's to the problem of making some appraisal of the ultimate reserves of the various metal ores. Though this approach may only be empirical, it is felt that it is not unreasonable to suppose that during the exploitation of a high-grade deposit, high-grade or low-grade extensions to the ore zone will be discovered. Occasionally an isolated deposit is encountered but it is believed that the recognition of mining "districts" in itself implies a geometric

relationship and that something akin to a growth curve can be used to describe the year to year growth and decline in output from a particular area. This growth characteristic is illustrated by Figure III-3 which shows the silver output of the Cobalt area and the gold output of Porcupine and of Kirkland Lake.

It has also been reported that the output of copper from the Upper Michigan deposits "fits Lasky's curves" though unfortunately this author, a reviewer of a book describing the economic history of mining in that area, was not more explicit.*

A further factor that could be relevant in this respect and which does not seem to be too far-fetched is the supposition that ore-bodies are discovered according to statistical chance. This is not to say that some areas are not more favourable than others, but that recognition that an ore deposit is present is a matter of pure chance once an area has become populated.

These suggestions, that the output of a mining district is related to the geometry of exploitation and that the discovery of ore-bodies is a chance occurrence, have not been put forward as the basis for a law of supply of mineral products: rather the intention has been to indicate that an empirical approach may not be completely barren. In passing it is worth noting that when an ore deposit is exploited by one company the rate of mining is likely to be a business decision and may follow a quite different course from those illustrated by Figure III-3.

*A review of "An Economic History of the Michigan Copper Mining Industry" by W.B. Gates and published by Harvard University Press, that appeared in Economic Geology, vol. 47, pp. 227-9 by T.M. Broderick.

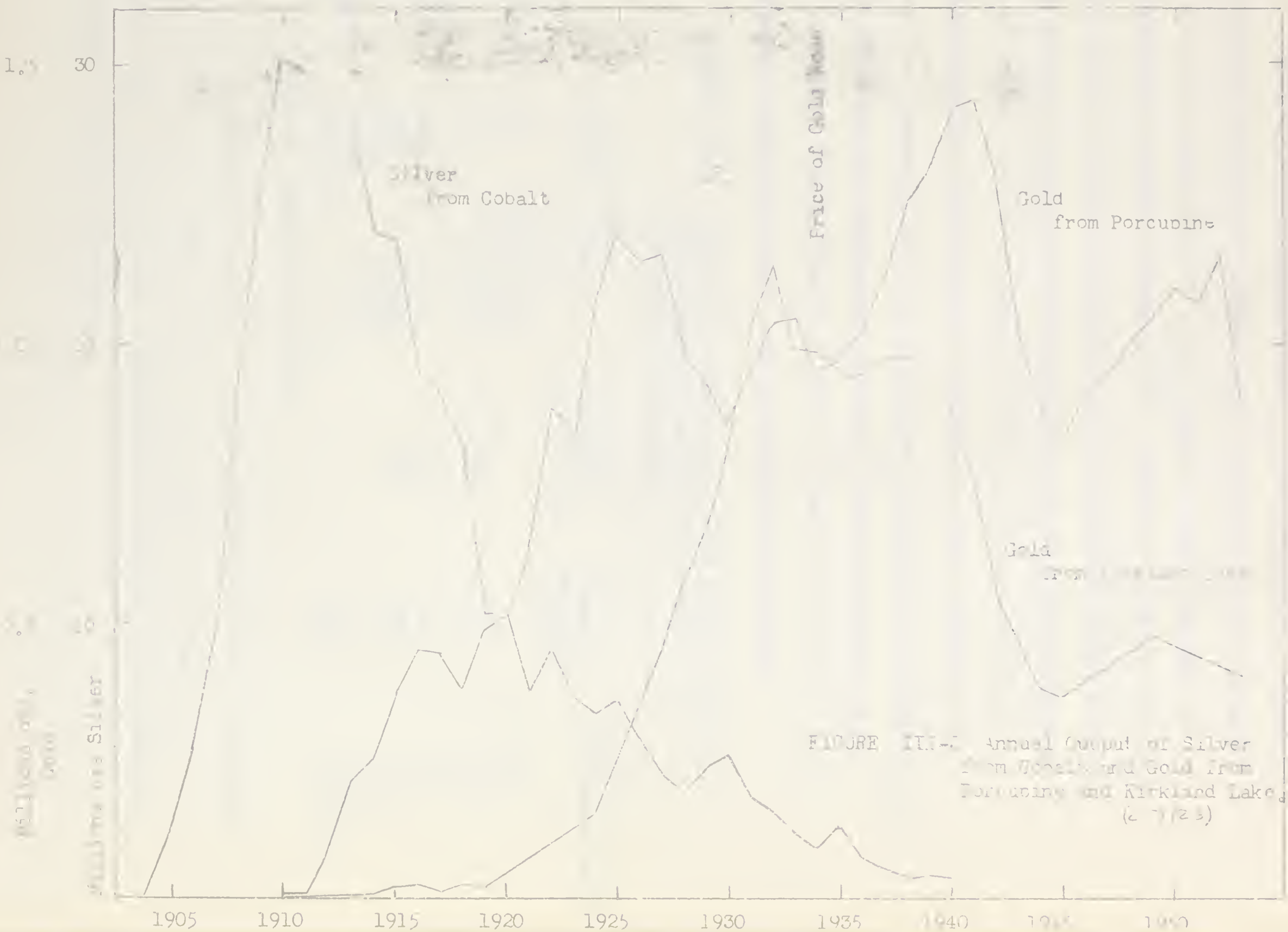

FIGURE III-[illegible] Annual Output of Silver from Cobalt and Gold from Porcupine and Kirkland Lake, ([illegible])

Another interesting approach to this problem of inflating the measured reserves to provide some indication of the ultimate supply of the various metals in the earth's crust, was made by F. Friedensburg and E.W. Pehrson[26,27]. They have compared the total metals content of the lithosphere, to two kilometers deep, with the known reserves. Table III-8 lists the calculated figures together with the latest figures for known and measured ore reserves as presented earlier. There appear to be some serious discrepancies between the composition of the lithosphere suggested by Friedensburg and Pehrson and that suggested by Walker[28]. This disparity is not very important. The key factor is the occurrence of deposits of the minerals in high-grade zones that can be mined effectively.

TABLE III-8 Comparison between the Total Metals Content of the Lithosphere and the Metal Content of Measured Ore Reserves.

Metal	Lithosphere Average %	Lithosphere Tons billions	Measured Reserves billions tons	Ratio total to measured $\times 10^{-6}$	Average Comp. of Igneous Rocks* %
Aluminum	7.48	58,366,000			8.13
Iron	4.7	36,674,000	126	.29	5.01
Zinc	.017	133,000	.084	1.6	.004
Nickel					.02
Copper	.010	78,000	.170	.46	.01
Lead	.003	23,000	.05	.46	.002
Tin	.0005	4,000		.6	.000n
Uranium	.00042	3,300		.1	.008
Gold	$.0001\times10^{-3}$	.8		.027	$.00n\times10^{-3}$

*Figures suggested by Walker

The up-grading required to obtain commercial ores of aluminum and iron is not very great, being of the order of 10 times. For copper, lead, zinc and nickel up-grading by a factor in the hundreds is needed to secure ore grades.

In view of the figures in Table III-8, it appears that it is much less likely that there will be a shortage of workable deposits of iron or aluminum than for the other metals. Unfortunately, geochemistry, at its present state of development, gives only the most tentative explanation as to the processes of emplacement of ore deposits, their grade and their location. The approach of Friedensburg and Pehrson thus provides only a partial picture of the ultimate supply of metals.

A simple calculation, see Appendix V, suggests that the ratio of hidden, though workable, deposits to deposits with substantial surface showings is of the order of ten to one for a 100,000,000 ton ore body of specific gravity of 4.0 assuming that ore can be mined to depths of 10,000 feet. This calculation is also based on the supposition that the ore body is quite compact, in fact a spherical form is used, and that there is an equal probability of the ore body occurring at any point within the 10,000 foot depth range. This latter assumption is supported by Walker[29], who contends that mineralisation occurs at depths between 250 feet and 3 1/2 miles beneath the earth's surface, if one takes into account the effect of erosion and weathering. The chances are that larger and less regularly shaped deposits are more likely to have significant surface showings than small, compact, deposits though it may be difficult to recognise an extensive ore body when a surface showing of an irregular formation is encountered.

Much of the earth's surface has some covering of vegetation or soil, so impeding the detection of mineralisation, but this factor is to some degree offset by topographical features which help to

create showings of deposits that would, according to the calculation, remain concealed.

It is thus not possible to say more than that there is probably several times as much ore remaining in large concealed ore bodies as has already been discovered by surface showings. Any advances in the techniques for detecting sub-surface deposits is thus likely to bring about significant increases in the known reserves of mine grade ore.

A second source of metals is from scrap and other secondary sources. It has been calculated that in 1957 there was over 30,000,000 tons of copper and 1,500,000,000 tons of steel in the United States that could be salvaged for ultimate remanufacture[30,31]. During the same year about 1/2 million tons of copper, over 400,000 tons of lead and 75,000 tons each of zinc and aluminum were recovered from old scrap.* In addition, about 25,000,000 tons of old steel scrap is consumed each year by the United States steel industry[32]. Other industrial countries, such as the United Kingdom, Germany, France, Japan and many others consume large quantities of scrap metal.

The accumulated stock of metals thus constitutes a very important reserve of metals, and as equipment, buildings and so on are replaced year by year, a supply of secondary metals arises continually. The quantity of secondary metal, and this only includes old scrap, depends upon a number of factors which can be related approximately according to the equation thus:

*New scrap is generated by fabrication processes while old scrap is collected from the salvage of obsolete equipment.

$$S = \sum s\, C_{-L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

S = tons of old scrap available each year
s = proportion of the metal originally used that is subsequently salvageable
C_{-L} = consumption of the metal in the original equipment when new "L" years ago.

The factor "s" depends much upon the use to which the metal is put. Thus if a metal is used as a thin protective coating, either a metallic plate or as a chemical paint compound, it is much less readily recoverable than if it is employed in its original application as a heavy casting or section. Again if a metal is used as a substantially pure metal it is much easier to recover for re-use than if it were employed as a minor alloying constituent. Some scrap metals, such as aluminum, cannot be cheaply refined and thus secondary aluminum is often used to manufacture alloys of successively lower aluminum content or to make alloys with additions of the pure metal.

There are also losses of metal due to corrosion and due to a physical dispersion related to wear, abrasion and "scatter" that occur inevitably with use.

Iron is used almost entirely in the metallic form and is largely recoverable though corrosion and dispersion do cause a wastage which is accentuated by the low value of the metal.

Copper is also used almost entirely in a metallic form, the only exception being in the relatively modest consumption in chemical form. The more important copper alloys are of sufficiently high copper content to justify remelting or refining to recover the copper content.

Lead is easily recovered from scrap and sustains very little wastage from corrosion, but large quantities (16% in 1958 in the

United States) were used in the manufacture of lead tetraethyl and over 7.5% for lead oxide compounds used in paints[33]. These two latter uses represent a complete loss of the metal.

Zinc consumption is somewhat concentrated in uses where salvage recovery is difficult. Over 40% of zinc is used in galvanising, 15% in zinc oxide while further quantities are consumed in dry cells[34]. Some zinc is recovered from the remelting of brass scrap, but even here the treatment is often directed towards the recovery of copper which is the major constituent both in terms of weight and value.

Aluminum, though it is almost entirely used in a metallic form, as already noted, is not readily recovered in a refined state from scrap, and thus secondary aluminum is usually employed only for alloys of relatively low aluminum content. Secondary aluminum can also be added to the virgin metal to provide the alloying elements needed, but there are obvious limitations to the use of this procedure.

Nickel presents an interesting case. In 1957 about 20% of the nickel consumed in the United States was used in the manufacture of stainless steel. Stainless steel scrap can now be remelted and used in the manufacture of new stainless steel, but refined nickel cannot be recovered from this source. About 35% of nickel is used in non-ferrous and high temperature alloys; nickel consumed in this form allows some recovery, but these alloys are by nature refractory in properties and critical in application which precludes remelting. The balance of the nickel is used for plating, about 10%, and in low alloy steels and cast irons from which the metal, effectively, cannot be salvaged. Secondary nickel recovery is relatively low

when one considers the value of the metal and its corrosion resistance. This low recovery is due to the forms in which the metal is used and to the technical difficulties encountered in handling these materials.

The period which elapses between the original use of a metal and its reappearance as secondary metal is also an important factor as recognised by the equation. The lead in batteries may be re-processed within a few years of original use while steel in buildings may be removed from circulation for fifty years. A number of estimates have been made of the stock of metals, and of the possible recovery by reclaimation, and these have been combined in Table III-9.

It is apparent that secondary metals, in the case of copper and lead and steel, constitute an important reserve of metals. If the use of the metal in total is increasing rapidly, scrap or secondary supplies are likely to be much less important than where the rate of use is relatively static. Thus the percentage recovery of aluminum is expected to be almost as high as that of lead, but, since the consumption of aluminum is increasing so rapidly, very little scrap is available at present from the relatively small output of former years.

TABLE III-9 Recovery of Secondary Metals in the United States.

Metal	% of present consumption from secondary sources	Recovery of Metals from output as secondary %[32]
Iron	25	65
Copper	25	65-75
Lead	40	40-60
Zinc	5-10	20-25
Aluminum	3- 5	40
Nickel*	3- 5	20

*Does not include nickel in secondary stainless steels.

Source: Minerals Yearbook, 1958, Volume I, Metals and Minerals (except Fuels) appropriate pages.

Thus if a relatively large proportion of the metal used can ultimately be recovered and re-used, and if the consumption of the metal is not rising rapidly, then scrap could supply a major proportion of total requirements rather than a minor amount as is now the case. The period, L, between which the metal is originally used and when it is scrapped and re-used, will also be significant since, for a given rate of growth in consumption each year, the shorter this period the more important scrap will be in supplying total requirements. Thus if equation (4) is modified to take into account primary as well as secondary metal supply as follows:

$$T = P + S$$
$$= P + \sum s\, C_{-L} \quad \ldots\ldots(5)$$

where T = total supply
P = supply of newly mined metal

the larger the supply of secondary metal the smaller the supply of new metal needed to secure a particular total supply. The supply of secondary metal will be directly affected by the value of "s" and of C_{-L}. If the rate of growth in consumption is low, (i.e. T/C_{-L} is close to 1,) which is more likely to be so if "L" represents a short rather than a long period, then the supply of secondary metal will be large in comparison to the total requirements. In some cases it is thus possible to visualise mined metal being a balancing rather than a predominating factor in the total supply.

No mention has been made thus far of the effect that the price of metals might have upon the supply of secondary metals. This omission is made because it is believed that the long-term effect of price changes would be relatively slight. Certainly high metal prices will increase the diligence of scrap collectors and justify

operations of a more intensive and extensive nature. However, it is unlikely that high scrap metal prices cause industry to replace its equipment prematurely, since salvage values are rarely more than a small proportion of the cost of new equipment. Furthermore, the effect of price changes in such cases will be reflected only in changes in the value of "L" which are of minor significance in determining the quantity of secondary metals made available in the long run. On the contrary, it seems quite possible that the quantity of scrap generated year by year is not significantly related to the demand for scrap.

To summarise the findings of this chapter, Table III-10 has been prepared.

TABLE III-10 Reserves of Primary and Secondary Metals (millions of tons of metal).

Metal	Primary: Measured Reserved	Primary: Additional Inferred	Secondary: Total Output of Primary	Secondary: Store of Metals	Secondary: Output of Primary 1947-1958
Iron	126,055	very large	--	3,000	
Copper	170	--	117	76	37
Lead	49	16	106	64	21
Zinc	84	80	98	25	33
Aluminum	2,850	very large	44	18	29
Nickel	7	42	4.6	1	2.3

The figures for the reserves of new metal are taken from the tables already presented. As indicated earlier, iron and aluminum are virtually inexhaustable on a world-wide basis due to the high content of these metals in the earth's crust.

The task of making a complete inventory of the world's stock of metals in use is formidable, as is an estimate of how much of this stock might eventually be recovered. However, this undertaking has

been attempted by Miller, and using his figures and method the store of metals that might be recovered has been calculated[35].*

It is apparent that the supply of metals that might ultimately be recovered from metal in use is almost as large in some cases as the metal in the measured primary reserves. These reserves of secondary metals are thus very important to any consideration of the supply of metals.

An evaluation of the adequacy of these stocks and reserves of metals in meeting future consumption requirements is left to the next chapter.

*The method used by Miller is only justified if the rate of production of metals is increasing rapidly. Thus the figures for copper and lead are not very reliable due to the fact that he does not allow for the scrapping and re-use of secondary metals. This inaccuracy is of a second order of magnitude and is only of significance where a high recovery of secondary metal is obtained and where new metal production is increasing slowly.

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Chapter IV

The two preceding chapters dealt with demand and supply for the metals iron, copper, lead, zinc, nickel and aluminum. In this chapter demand will be related to supply, on a world-wide basis. An attempt will then be made to assess the rôle that the potential mineral resources of Northern Canada could or should play in providing a part of the metals consumed by the world. It should be noted that for the supply of metals, reserves rather than current production rate is the concern of this paper and that the geographical area denoted by the term "Northern Canada" has been defined in Chapter I.

Taking first the demand and supply of iron ore; Table IV-1 illustrates the situation for each of the important economic areas. Due to the very wide distribution of iron minerals throughout the earth's crust, figures showing the grade of the ores are also included to indicate which locations are most favourably endowed.

TABLE IV-1 Demand and Supply for Iron Ore (millions of tons Fe).

Area	Total Consumption 1955 to 1980	Reserves	Overall Grade
United States	2,350	20,086	31.4%
Canada	125	5,327	39.0%
Western Europe (excl. U.K.)	1,700	6,449	44.0%
United Kingdom	440	1,215	26.4%
Eastern Europe (incl. U.S.S.R.)	2,050	19,080	31.7%
Soviet Asia	615	3,576	32.0%

TABLE IV-1 Continued

Area	Total Consumption 1955 to 1980	Reserves	Overall Grade
Japan	288	27	42.1%
Asia (excl. Japan and S. Asia)	--	39,738	36.1%
Africa	--	5,288	54.1%
South America	--	24,991	41.5%
Totals (including others not listed individually)	8,250	126,055	--

It is apparent that the reserves of the world are very large and will, in all probability, still be large when technology has reached a stage, in the far future, where steel has become less important. The indications are that the United States has large reserves of iron ore even though the grade of ore is low by present standards. This ore has, for the most part, to be beneficiated before it can be used economically for iron or steel-making.

The iron ore reserves of Western Europe are much more slender, particularly when one takes into account that almost half of these reserves are the low grade Lorraine Minette ores. The situation is even less favourable in Britain where, not only are the ore reserves low, but also they are of low grade. However, some distinction must be drawn between the low grade ores of Europe and Britain and those of the United States. The former are self-fluxing and have been used directly as furnace feed for many years. The low-grade ores of North America are typically taconites which are high in silica and which must be beneficiated to remove this impurity.* Even with

*After an initial reluctance to accept pellets or sinter prepared from iron concentrates, these materials have proved to be so satisfactory for feed to blast furnaces that ores that previously were of sufficiently high grade for direct use are now beneficiated.

supplies of ores with these self-fluxing characteristics, high grade ores are imported by Western European countries for blending with the domestic material. The quantity of foreign ore so used is increasing yearly.

Eastern Europe, including the U.S.S.R., is well supplied on an overall basis although neither the grade nor the location of the reserves are particularly favourable. Thus Czechoslovakia and Poland import high grade ore from Sweden, other Western European countries, and from India[1,2].

Soviet Asia is well supplied with iron ore, considering its output of ferrous products, but Japan is virtually without iron ore resources. This latter country imports ore from many producers in S. Asia and bordering on the Pacific. Parts of Asia other than the Soviet territories and Japan, South America and Africa all have large reserves of very high-grade ores. Countries of particular wealth in this respect include India, Brazil and Venezuela.

It is apparent that the larger steel producing areas - the United States, Western Europe and Russia and her economic bloc - are adequately endowed with ore reserves; these deposits are, however, much less rich than those of other areas and there is little doubt that the first two will continue to import high-grade ore from Africa, South America and Canada and later from India and from the other less well-developed countries. The western members of the Soviet bloc in Europe and even the U.S.S.R. herself may also pursue the same policy if no high-grade deposits are found within their territory and if political conditions allow. On the other hand African iron

ore supplies may be withheld periodically from Western Europe and North America during periods of political unrest. At present imports of iron ore are taken almost entirely by the developed countries and, although these imports represent only 30% of the total consumption, they are all of material of higher grade than domestic supplies. In the past many nations have attempted to develop their own steel industry for political and strategic reasons rather than from strictly economic motives, and these factors, to some degree, explain some of the apparent anomalies in the sequence of development of ore reserves[3].

A second consideration of significance is the large stock of scrap iron and steel available. As previously noted this stock is estimated to have stood at 1.5 billion tons in the United States in 1958 and the world total could easily be double this figure. It should be noted that scrap iron and steel is usually a more important raw material in the developed than in the underdeveloped countries. Thus if the tonnage of pig iron manufactured directly from iron ore is expressed as a percentage of the steel output, the figure is 70% for North America, 85% for South America, 70% for Western Europe and 90% for Asia[4]. Recognising that some pig iron is used directly in foundries, these figures indicate that technology in the less well developed countries is more dependent upon new pig iron than re-used scrap as a raw material for steel-making. The emergence of new fast-growing economies together with the development of oxygen processes for steel-making which consume about half the scrap required for open-hearth furnaces, suggests that there will

be plenty of scrap available to supplement natural sources of iron.[*] In recent years old scrap consumption amounted to about 15% of the net steel output. This quantity of iron is thus a direct supplement to that which comes from iron ore via pig iron.

TABLE IV-2 Demand and Supply for Copper (thousands of tons Cu).

Area	Total Consumption 1955-1980	Reserves
United States	40,000	32,500
Canada	4,125	7,000
Western Europe (excl. U.K.)	30,650	1,200
United Kingdom	14,100	--
Eastern Europe (incl. U.S.S.R.)	22,750	16,000
Soviet Asia	1,840	--
Japan	7,200	--
Asia (excl. Japan and Soviet Asia)	--	--
Africa	--	45,600
South America	--	58,500
Totals (incl. others not listed individually)	136,500	170,000

The demand and supply position for copper is presented in Table IV-2 . Totals indicate that the world's reserves are adequate for the next twenty-five years even accepting the substantial consumption increases predicted. The ore reserves in the United States, though almost sufficient at the present rates of consumption, would not cover requirements at a 1.5% per year rate of increase. Canada's resources are more than enough for her own requirements but would not go far in supplementing the domestic reserves of the United States.

[*]This conclusion is at variance with the view expressed by the Paley Report which anticipated a shortage of scrap.

Western Europe and the United Kingdom are almost completely dependent upon overseas supplies since domestic prodcution of new copper is small in both cases. Eastern Europe is greatly dependent upon new copper from the U.S.S.R.; apparently only East Germany has any mine production and this amounts to only half of that country's consumption[6].

Japan, the other large consuming area, also imports large quantities of scrap and new copper.

The large exporters of copper are located in Chile and Peru and Northern Rhodesia and the Belgian Congo. The ore reserves of these countries together account for more than 50% of the world's known resources, although production is substantially less than 50% of the annual world output. This deficiency is due, in part, to implicit and actual measures taken to encourage domestic production, so far as is feasible, in a number of consuming centers such as the United States and Japan.

The supply of copper from mining operations is extensively supplemented by secondary copper. As indicated in Chapter III, the "in use" stock of copper in the United States at present is about 30,000,000 tons and thus the world stock is probably of the order of 60,000,000 tons. Statistics on the use of secondary metals are often somewhat unreliable due to the difficulty in distinguishing between old and prompt scrap. However, it appears that in industrialised countries scrap, old and new, accounts for 35 to 50% of the total copper consumption[7]. The rate at which the consumption of copper is increasing will have an effect on the proportion of copper derived from secondary sources as will the history of usage. Table IV-3

illustrates this point.

TABLE IV-3 Approximate Percentages of Copper Consumption Derived from Secondary Sources.

Country	% of Secondary Copper (old and prompt purchased) 1954	1955	1956	1957
United States	37.0	44.9	43.9	41.8
United Kingdom	36.5	39.5	36.9	34.7
West Germany	54.9	55.6	53.4	39.5
Italy	44.0	50.5	40.0	34.0
France	41.4	41.5	44.5	41.0
Japan	40.1	40.9	47.6	48.9

It is evident that Germany rapidly exhausted its stock of accumulated old copper after the war, so that by 1957 the ratio of scrap to total copper fell to a more usual figure. A similar situation prevailed for Italy. United States and United Kingdom consumptions of secondary copper have been fairly consistent, while the Japanese consumption has climbed steadily. In recent years Japan has imported increasing quantities of scrap in an attempt, no doubt, to secure copper in its least processed form.*

If the old scrap alone is taken a somewhat lower figure is obtained. In the United States about half the scrap consumed was prompt scrap and thus the percentage of old scrap, on a net total output basis, comes to approximately 25%.

The demand and supply relationship for lead is illustrated by Table IV-4. It will be noted that even if no gain in consumption of lead occurs, reserves would be barely sufficient for the next twenty-five years. If a moderate rate of growth in consumption occurs, some shortage must thus be expected. Once again none of the

*It is worth noting that very little copper concentrate is marketed as such; if not smelted close to the mine, it is shipped to a smelter owned by a subsidiary of the mining company or is handled on a long-term contract basis.

large consuming areas has sufficient reserves for its requirements over the next two decades. This situation is true both for the Soviet countries and the western countries, so far as one can judge. In this respect it is interesting to note that within the Soviet economy lead is priced at 25% above that of copper[8].

TABLE IV-4 Demand and Supply for Lead (thousands of tons of Pb).

Area	Total Consumption 1955-1980	Reserves
United States	20,400	2,910
Canada	1,670	8,033
Western Europe (excl. U.K.)	20,000	9,100
United Kingdom	5,800	--
Eastern Europe (incl. U.S.S.R.)	14,100	4,600
Soviet Asia	3,050	
Japan	2,880	2,000
Rest of Asia	--	
Africa	--	3,500
South America (incl. Mexico)	--	6,025
Australia	--	12,500
Totals (incl. others not listed separately)	72,100	48,818

Large reserves of ore exist in North Africa, Mexico, Peru, Australia in addition to those in Canada and these all, to a greater or lesser extent supply the United States, Western Europe and Japan with lead. In 1958 the Soviet bloc appeared to be a net exporter of lead[9].

However, as already indicated, see Chapter II, substitution is a particularly potent factor in the case of lead and rapid price increases cannot be expected. The consumption of lead has shown only a slight increase in the past ten years in the United States though elsewhere more rapid growth has taken place. How much this

more rapid growth rate is due to the regaining of pre-war living standards is hard to assess exactly. There is some indication that the substitution in the United States of other materials for lead may have gone as far as is feasible for the time being.

The supply of new lead is supplemented by significant quantities of secondary material. Records suggest that about one third of the world's lead supply in recent years has been derived from scrap[10]. Since 1948 the quantity of secondary lead consumed has remained fairly steadily at about 1,000,000 tons per year. A further relevant factor is that the secondary metal is obtained almost entirely (85-90%) from old rather than prompt scrap and represents an actual addition to the net amount of metal available for consumption[11].

The surplus of lead that appeared during the last few years has been due, in some degree, to political considerations. Certainly the consumption of lead has not increased as rapidly as a number of the other non-ferrous base metals, as for instance copper, but, also, determined efforts have been made to preserve and succour the domestic United States mining industry against foreign competition based on significantly higher grade ores[12].

The world-wide overall supply and demand situation for zinc over the next twenty-five years is indicated by Table IV-5. At the estimated increased consumption, adequate supplies exist when taking into account inferred reserves. North America as a whole is self-sufficient (it has a considerable surplus with Mexico's 6,650,000 tons). Western Europe, the United Kingdom, Eastern Europe and Asia together

have considerable resources which,however, may ultimately need supplementary imports. Considerable exports of zinc have been made by the U.S.S.R. to western countries in recent years.

TABLE IV-5 Demand and Supply for Zinc (thousands of tons Zn).

Area	Total Consumption 1955-1980	Reserves
United States	28,200	13,485
Canada	2,190	16,691
Western Europe (excl. U.K.)	20,000	11,000
United Kingdom	7,800	--
Eastern Europe (incl. U.S.S.R.)	14,000	11,000
Soviet Asia	6,750	
Japan	6,890	4,500
Asia	--	
Africa	--	4,000
South America (incl. Mexico)	--	12,650
Australia	--	11,000
Total (incl. others not listed separately)	91,000	84,501

Among the large zinc exporting countries are Mexico, Peru, Australia, Belgian Congo and Morocco, as well as Canada.

The supply of zinc from secondary sources is much less important than that for any of the three metals already discussed. In recent years 20 to 25% of the annual production of zinc was obtained from secondary material rather than from mined ore[13]. Of the total of secondary material about 70% was prompt scrap and the two largest sources were zinc base die-casting alloys and brasses[14].

In addition to the zinc ore and secondary materials used for the manufacture of metallic zinc, quite substantial quantities are used for the production of zinc oxide and other compounds for the paint industry. The total of zinc used in these zinc chemicals

usually amounts to about 150,000 tons per year in the United States and all of this, except 15-20,000 tons of slab zinc and about 35,000 tons from secondary material, comes directly from ore[15]. The figures for the world would approximately be double the totals for the United States.

A comparison of the world supply and demand for nickel has been drawn up and is presented in Table IV-6. The overall situation portrayed is one of ample reserves. However, as indicated in Chapter III much of the nickel in these reserves is likely to be more costly to recover than that mined at present.

TABLE IV-6 Demand and Supply for Nickel (thousands of tons of Ni).

Area	Total Consumption 1955-1980	Reserves
United States	4,600	550
Canada	210	6,332
Western Europe (excl. U.K.)	1,930	87.5
United Kingdom	960	nil
Eastern Europe (incl. U.S.S.R.)	2,110	1,300
Soviet Asia	--	--
Japan	165	315
South-East Asia	--	10,000
Oceania	--	16,500
South and Central America	--	18,000
Total (incl. others not listed separately)	10,000	53,084.5

Canadian reserves will make North America self-sufficient for the next twenty-five years. Canadian reserves could also go a long way towards supplying the requirements of Western Europe and the United Kingdom. The nickel in the Canadian ore reserves can be almost entirely recovered at the present real prices for the metal.

Eastern Europe, including the U.S.S.R., appears to be short of nickel. It has been reported that the U.S.S.R. is purchasing nickel at present from the western countries[16]. Japan, potentially another large consumer, appears to have adequate reserves, but in practice production costs are too high and a supply of ore and concentrates is purchased from British Columbia, from New Caledonia and from elsewhere.

Large reserves of nickel ore in the oxide form occur in Cuba, Venezuela, Brazil, Philippines, Indonesia and other tropical regions. Processes have been developed for the recovery of this nickel and apparently many of these deposits are close to being commercially exploitable. It is believed that if the price of nickel rose, at the present general level of prices, to $1.00 per pound, virtually unlimited quantities of the metal would become available. On the other hand, in at least two of its important uses, there are no convenient substitutes for nickel. Nickel in steel-making plays an essential rôle and in high temperature applications nickel at $1.00 per pound is significantly cheaper than any other metal with the same high temperature stability[17,18].

The supply of nickel seems quite secure for although, apart from the Canadian deposits, the principal resources are situated in politically unstable countries; it is unlikely that all of these deposits will remain inaccessible to both the West and the Soviet bloc.

Secondary nickel, excluding that in scrap stainless steel, accounts for about 10% of the consumption of nickel in the United States most years[19]. No detailed figures are kept on the quantity of secondary

nickel in the form of ferrous alloys, nickel-chromium and high temperature alloys that is used by the steel industry. However, in the period 1955-56, 10 to 12% of the total nickel consumed was secondary material remelted directly in the manufacture of steels of various types[20]. How typical the figures of this one period are is hard to say, since during 1955 and 1956 there was a serious shortage of nickel in the western countries.

On an overall world basis, the reserves of aluminum ore are ample: indeed when one takes into account the high percentage of aluminum in the earth's crust, it is apparent that deposits of <u>some</u> grade or mineralogy must always be available. Even though ingenious, if costly, processes have been developed for the recovery of an aluminum ore from clay, a premium is still placed on high grade, easily processed bauxite ores. The United States and Canada, as the world's leading producers of ingot, are notably short of suitable ore deposits. However, the resources of the Caribbean and of South America are plentiful and accessible.

Western Europe is, apparently, self-sufficient though about half of the known reserves are in Yugoslavia and are relatively undeveloped. Western Europe and the United Kingdom draw on bauxite deposits in Guiana and Africa. Eastern Europe, Soviet Asia and Australia all have extremely large reserves though the U.S.S.R. has been a pioneer in the treatment of non-bauxite aluminum ores. It has been estimated that it costs only 8% more to recover aluminum from nepheline syenite ores than it does from bauxite under comparable conditions[21].

Japan is deficient of any considerable deposit of aluminiferous ore.

TABLE IV-7 Supply and Demand for Aluminum (millions of tons of Al).

Area	Total Consumption 1955-1980	Reserves (contained Al)
United States	105	22.4
Canada	5.4	--
Western Europe (excl. U.K.)	52.5	124.0
United Kingdom	19.9	--
Eastern Europe (incl. U.S.S.R.)	48.1	165.0
Soviet Asia	7.8	265.0
Japan	4.8	--
Rest of Asia	--	34.0
South and Central America	--	357.0
Africa	--	1,181.0
Australia	--	511.0
Total (incl. others not listed separately)	250.0	2,659.4

In a number of ways the location of aluminum reduction plants is more dependent upon cheap sources of electricity than upon proximity of ore reserves, though accessibility of ore or cheap transportation facilities is also a matter of concern. Thus Canada's aluminum industry is the result of the availability of cheap power rather than the closeness of markets or ore supplies. Norway is in a similar position. With the development of power-sites in Africa, there has been in recent years, a trend towards integrated plants at the site of both the ore reserve and the hydro-electric generators.*

During the last decade the quantity of aluminum recovered from secondary sources amounted to 15-20% of the total consumption of the metal in the United States. This figure can be expected to increase in the years to come because the proportion of old scrap is at present very low, accounting for only about 3% of the total

*The Volta and the Inga projects are to be situated on the Volta and the Congo river respectively.

metal consumption[22].

In summary,it appears that the United States falls seriously short of self-sufficiency in lead and nickel. Secondary sources of lead will probably become more important in the future in the United States. The United States will be dependent upon Canada or some alternative outside source for supplies of nickel and will continue to import high-grade iron ore and bauxite to supplement lean domestic ores where such a procedure is advantageous. The United States will continue to import zinc.

The position of Western Europe is similar to that of the United States, though its lead supply is better and its copper resources are much less plentiful.

Japan and the United Kingdom are both very short of deposits of the six metals we are considering specifically. Britain has, however, large reserves of low-grade iron ore and Japan has some zinc deposits which at present sustain her consumption.

So far as one can tell, the position of the Soviet Union and her European satellites is quite similar to that of the United States in terms of the availability of mineral resources. It is difficult to draw conclusions about Soviet Asia due to a lack of information, published or otherwise.

Potential markets for Canada's exports of copper, lead and nickel thus could exist in the United States, the United Kingdom, Western Europe and Japan. Canadian producers could expect to meet considerable competition from domestic producers of copper in the United States, however. High-grade iron ore and concentrates could also be marketed in these countries. Canadian zinc may also be

supplied to all of these countries or groups of countries in the next twenty-five years.

Canadian aluminum will also hold a strong position in each of the industrialised areas, although, as already indicated, energy resources are the key to this situation.

The Soviet countries of Europe and Asia may also call upon Canadian metal exports if political conditions are appropriate.

We have tentatively established the potential markets for Canadian metal exports. It is now necessary to consider how producers in Northern Canada can gain commercial access to these markets. In the non-Soviet countries of the world, access is gained to the market by being able to supply metal at current prices. It is thus appropriate to consider briefly how prices are established for the six metals that have been discussed in detail, how prices might change in the twenty-five year period up to 1980 and under what circumstances could the Northern mineral resources be exploited profitably.

The first topic, that of how prices are established, is essentially a matter of market structure and characteristics. For metals, this question is one of such complexity that only a cursory discussion is attempted here. The markets for metals are unusual because a substantial proportion of many of these products are offered as undifferentiated commodities, and because a rich and extensive ore deposit can give the owner a measure of monopoly control over a sector of the market. Thus, while full control of the available ore reserves gives a considerable degree of discretion in setting prices, lack of control of industry output rates coupled with an undifferentiated commodity product allows the individual producer no power of price

setting. Generalisations of interest cannot be devised to cover all six metals and so each one will be discussed separately.

In the non-Soviet world, nickel and aluminum are probably the two important metals for which prices are most closely administered. For nickel the initiative lies with the International Nickel Company. This company accounts for more than half of the output of nickel of the Western countries. Its leadership has not been seriously challenged for fifty years. The strength of the International Nickel Company lies in its ore reserves.

The price of nickel has not been cut in recent years to meet slackening demand, output is merely curtailed until business activity recovers. The Company's competitors have indulged occasionally in price shading, but there has been no retaliation[23]. Furthermore, only a proportion of the Company's output is an undifferentiated product. A considerable proportion (about 30% by weight) of its sales are in the form of proprietory alloys and semi-manufactured materials. None of the other nickel producers have attained a comparable degree of product differentiation or vertical integration.

Although differing from the nickel industry, where price leadership is the outcome of a strong raw material position, the aluminum industry does not allow the free fluctuation of primary metal prices. The industry is probably the most concentrated of any of the metals industries, the producers having many of the characteristics of oligopolists. Freedom of entry is restricted in this case by the requirement of ample capital resources, the availability of cheap and plentiful energy and technically competent personnel. Davis estimates that the four large producers in North America account for

nearly 70% of the world's output while eight concerns in the Western countries control about 90%[24].

Price adjustments are apparently made by a decision within the industry, motivated to secure the best operating conditions for the industry. The Aluminum Company of America has maintained price leadership in North America for many decades in the past. Probably the only time that a precipitate price adjustment has been made was when the U.S.S.R. entered the world market bringing in 1958 a drop of 2¢ per pound in the price of the metal.

The primary aluminum industry has also attained a fair degree of vertical integration. Thus consumer goods such as foil and cooking utensils are marketed, on occasions, under the name of the primary producer.

The producers of secondary aluminum do not really compete with the primary producers since they cannot produce ingot of the required purity. There is a fluctuating price for the secondary ingot and,in fact, the market is quite different, there being a large number of small producers. The market for secondary aluminum has, as yet, little effect on that for the new metal.

Iron ore prices do not fluctuate on a day to day basis; price adjustments are usually embodied in agreements, of the duration of the shipping season, between the ore producer and the steel-maker purchaser. The steel industry is well known for its product pricing practices and the strength and structure of this industry has a profound effect on the iron ore producers. As noted in "Mineral Facts and Problems":

> "The Lake Erie base prices are established each year by the publication of a major contract between a prominent producer and a steel company"[25].

However, as is also pointed out, only a small proportion of the ore from the Lake Superior deposits comes from the independent producers and over 75% from the captive mines of the steel companies. Imported ore very frequently also comes from mines controlled by the steel-makers they supply. Probably the Swedish iron ore producers are the most significant exception to this situation. The most important factor in the establishment of iron ore prices is thus the continuing trend towards vertical integration in the industry. There is little scope for product differentiation although steel producers do favour ores and concentrates in certain forms.

The markets for copper, lead and zinc are much closer to those of an undifferentiated commodity with numerous suppliers and buyers than those for the metals discussed already. Price stability is continually eroded by surpluses or shortages that actually reach the market. This instability is to a considerable degree, as we shall see, brought about by custom scrap and concentrate processors who are unconcerned by the price level, so long as the margin between their buying and selling prices are sufficient to cover the costs of their own operations. Low price levels do not always curtail the supply of unrefined secondary metals although the quantity of concentrates available would be responsive to price changes. In addition to the custom smelters and refiners, who adjust prices with changes in demand, all three of these metals are actively traded on the London Metal Market and the Commodity Exchange in New York. The

actual tonnage of metals that is at the disposal of these markets is relatively small, but price fluctuations indicated by the trading provide the lever for the custom smelters.

The primary copper industry is dominated by half a dozen large international integrated producers which together control a large proportion of the world's copper ore reserves. However, these organisations are faced by large custom smelters who, whether they process scrap or concentrate, are concerned with keeping their process plant fully occupied.

Thus, although the copper industry might otherwise have been oligopolistic in nature, the custom smelters appear to have made such a situation impossible. The price of copper fluctuates regularly, with the response of the primary producers being the slowest and that of the exchanges the most rapid. This problem of price fluctuations has been a matter of considerable concern in recent years due to the vigour of the competition from aluminum and the larger primary producers all make "voluntary" cuts in output in anticipation of metal surpluses. So far as is known the custom smelters rarely exercise such restraint.

Some degree of vertical integration has been undertaken by the industry but the products still remain virtually undifferentiated.

Lead has all the characteristics of the copper industry with, perhaps, the difficulties aggravated to some degree. The lead industry is in many aspects a declining industry and thus market instabilities are intensified in certain respects. The large primary producers are not able to exercise an effective price leadership and scrap reprocessing can be carried out economically on a very small scale.

Very little vertical integration or product differentiation has been attained by the primary producers, although the one large secondary producer has a big share of the pigment and paint market. Other important users of lead, the tetraethyl lead and the battery manufacturers are notably independent of the primary metal producers.

The primary zinc industry is less concentrated than the copper industry and perhaps less so than the lead also. Scrap is not an important problem here though custom smelting is a potent factor. Probably the most significant characteristic of the industry is the degree to which the metal is a co-product of other metals; zinc output is thus not uniquely determined by the demand for zinc.

Some of the zinc producers manufacture pigments and chemicals, but none is engaged in galvanising, the principal use for zinc and few in die-casting, the second most important application.

It is hardly appropriate to attempt to draw any conclusions as to the reasons for ordered price adjustments in the case of aluminum, nickel and iron ore and free price adjustments for lead, zinc and copper. However, where secondary metal competes with primary metal the former appears to act as a lever against any price stability that might be established by the latter; there is, in fact, a basic difference in the interests of the two groups. It should be noted that scrap steel does not come into competition with iron ore directly; these are merely two steel-making constituents which can be combined in varying proportions. Where secondary steel competes with steel made from iron ore a situation similar to that pertaining to copper, lead and zinc may result.

We can now consider how the structure and organisation of each of these industries might affect the exploitation of mineral resources

of the North. A company that is in possession of a deposit that allows it to produce at lower costs than all others is, ultimately, going to establish itself no matter what difficulties are placed in its way. Reluctance to develop a deposit could, however, depend upon a number of factors related to the structure of the industry. If there is no market for raw materials or intermediate products, a company may have to provide itself with a plant installation carrying the raw material to the semi-manufactured stage before it has a marketable product. Such conditions are going to act as a deterent to the less powerful concerns.

In the aluminum industry, for instance, there is little market for bauxite or aluminum and it is usually necessary for the producer to obtain facilities for producing ingot or semi-manufactures. Iron ore can be sold to steel producers, but intermediate products such as pig iron or ingot steel cannot be marketed readily. A producer, if he is not content with marketing ore, must usually go the whole way to the semi-manufactured materials.

Nickel concentrates can be sold for smelting and refining, but the market is not active. The nickel industry and the aluminum industry are concentrated and there is always some risk that the established producers will act in concert to discourage a newcomer.

Copper, lead and zinc are, however, readily marketed as ore, concentrate, refined metals or semi-manufactures. In addition, conditions approaching perfect competition are attained in the marketing of these metals. However, a new producer may feel reluctant to invest in an industry where his selling price and his profits are subject to such vagaries. Furthermore, due to the significance of transportation costs, a well situated smelter may have a considerable degree of discretion in the establishment of its treatment charges.

Thus far we have discussed the structure of each of the

industries involved. The next matter for consideration is an assessment of the supply and demand characteristics for these metal industries. The assessment has been made in terms of elasticities, and Table IV-8 shows some suggested qualitative values for both supply and demand. Some general comments can be made directly: all these elasticities are restricted to a relatively narrow price range which is of the order of ± 50% of a datum level corresponding closely to the current (first half of 1960) prices. (See Table IV-8.) It has also been assumed that prices of metals do not change greatly in relation to one another.

The elasticity of supply of each of the metals is, it is suggested, low for downward price adjustments. This is due to the large capital investment that is usually involved. The investment outlay for a fully integrated copper production unit is of the order of $2,000 per ton per year, for nickel it is somewhat more and for aluminum, including power generating facilities, somewhat less. Capital costs for zinc and lead are substantially less and steel is of the order of $300 per ton for an integrated plant. However, though it has been suggested that the response of supply to a downward adjustment of prices is likely to be somewhat sluggish, it must be recognised that the prices of steel, aluminum and nickel are largely administered. Output is cut, in the face of a mounting surplus of unsold product, by an industry-wide decision rather than by individual concerns in response to falling prices. However, if the supply of iron is considered only up to the point of shipping iron ore, where the investment per ton of output can still be relatively small, of the order of $20-50 per ton, a relatively responsive

supply situation can be expected to exist.

The production of steel, aluminum and nickel would be increased significantly if the market price rose as the result of a significant and sustained increase in demand for these products. An upward adjustment of output rates would not be limited in any way by a shortage of suitable ore deposits: indeed large deposits of minerals of each of these metals have lain unexploited for many decades.

TABLE IV-8 Metal Demand and Supply Elasticity.

Metal	Ratio, Current Ore Grade: % Metal in Lithosphere	Elasticity of Supply		Elasticity of Demand		Datum Price Level ¢/lb[26]
		price rise	price fall	price rise	price fall	
Iron	10:1	high	low	low	low	3.4
Copper	150:1	(low)	low	high	high	33.5
Lead	1,000:1	(low)	low	high	low	12.0
Zinc	300:1	(low)	low	high	low	13.5
Nickel	60:1	high	low	low	medium	74.0
Aluminum	5:1	high	low	medium	high	26.0

Note: Terms in brackets ( ) indicate long-term rather than immediate situation.

For lead, zinc and copper a rather different situation prevails. Any increase in production rate in response to a price rise is likely to be of a somewhat temporary nature characterised by the absorption of unused capacity. The unexploited deposits of these metals are quite rare, so differing radically from the situation for the three other metals. Referring to Table IV-8, this point is confirmed by a consideration of the ratio of grade of ore mined currently to the percentage of the metal in the lithosphere. A high ratio suggests that current reserves may not be backed up by other deposits of only slightly lower grade, while a low ratio implies that ore of a little lower grade is available to maintain

output.* It appears safe to conclude that the supply of these "old" non-ferrous base metals is inelastic for upward adjustments of price when the long-run prospects are considered.

Let us turn now to the suggested elasticities of demand for each metal. Steel does not face close substitutes in most of its uses, nor is the cost of steel at its present level likely to greatly affect the price of a finished article, and thus the decision to purchase such an article. The elasticity of demand for steel is therefore low; this conclusion is supported by Dean who, employing a procedure developed by Schultz, showed that a quantitative estimate in the order of .3 or .4 was likely[27]. The elasticity of demand for copper is high, it is believed, due to its vulnerability to substitution and to the relative ease with which it could replace aluminum if it once again became the cheaper metal.

Both lead and zinc have curved demand curves, concave to the origin. Price increases would soon lead to replacement by substitution of both of these metals while price reductions would bring few, if any, additional uses. In the case of lead it should be noted that currently about half of the consumption in the United States is taken up by batteries and tetraethyl, two uses for which there are no convenient substitutes for lead at present.

Nickel, on the other hand, does not appear to have any close substitutes and for a number of essential applications a moderate price increase would not curtail consumption significantly; this

*This is only a statistical argument and says nothing about the physico-chemical aspects of the problem: a high ratio implies a very wide deviation, a low ratio a much narrower deviation about the mean, which is taken in this case to be the percentage in the lithosphere.

conclusion is drawn because nickel is a minor constituent, in terms of its value, in many of its uses[28]. For similar reasons price reductions would not encourage greater consumption.

Price increases would hamper aluminum's capacity to replace other materials and would enhance a tendency for it to be replaced by other materials. The demand for aluminum is thus believed to be fairly elastic. Fisher came to the same conclusion and suggested a figure of 1.7[29]. Nickel and aluminum also have slightly curved demand curves though in these cases the curves are believed to be convex to the origin in the conventional diagram.

Let us now examine briefly the points that an organisation or individual would have to consider, having acquired a deposit of ore of these six metals. In most cases it will be relatively easy to assess whether or not the mine can be worked at profit, taking into account the grade of ore and the expenses that are likely to be involved. They might next consider whether or not exploitation should take place immediately or should be postponed, so that they can get a greater profit out of this irreplaceable resource.

The owner of an iron ore deposit in effect faces an administered price, and if he can find a market for his ore there seems little reason to postpone exploitation in view of the high elasticity of supply. A steel-making company may hold unexploited deposits in reserve, but this action is taken more to facilitate planning than to gain a market advantage.

Copper, lead and zinc deposits should also be exploited promptly, for once again extra high profits cannot be expected due to the high elasticity of demand with a price rise. The prices of

these metals are largely determined by the interplay of market factors with an additional complication of a large supply of secondary metals in the case of copper and lead. It is believed that when ultimately the supply of these metals becomes short due to exhaustion of reserves, prices will rise briefly, only to be forced down again by substitutions.

The exploitation of nickel deposits does leave a little scope for market strategy. As suggested earlier, it may be that nickel prices will have to rise to 90¢ or $1.00 per pound before non-sulphide deposits are exploited extensively. Until the non-sulphide deposits are exploited, the elasticity of supply may not be high and super-normal profits could be made by the well-situated producer.

The position of aluminum is in many ways quite similar to that for iron, except that lower metal prices with a much expanded market can be expected in the future. Once again there appears to be little benefit to be gained by postponing exploitation of resources. However, Canada's interest in aluminum is more in terms of power resources than as ore reserves and further consideration lies outside the limits of this study.

With these data and conclusions, there seems to be little justification for the suggestion that Canada should place an artificial restraint on the exploitation of her resources so as to profit by the ensuing world shortages since the possibility of significant price changes is small. Rather, it seems that Canada should proceed with the development of her mineral resources as soon as economic factors allow.

It is sometimes suggested that, for the benefit of the economy as a whole, exploitation of natural resources should be postponed until such time as all exports could leave the country in form of

manufactured goods rather than raw materials. Canada, it is argued, will need these metals in the foreseeable future for domestic consumption and for the manufacture of goods for export. As indicated in Chapter I, the form in which Canada exports her metal products is not entirely a free decision, since tariffs, as well as commercial and technical factors to some degree, frequently favour the export of raw materials. Nonetheless, a restraint on the export of raw materials could be made a part of a national policy on the exploitation of natural resources. It is, however, possible that such a policy would have an effect of slowing, for a number of years, the rate of growth of the mining industries which may well stunt rather than enhance the development of the secondary industries, taken as a whole.

Furthermore, we have concluded that a number of metals will be replaced by substitutes at an increasing rate when they become in short supply and their prices rise. Modern technology often produces a substitute that is better than the original, and it may well be that by the time Canadian industry has grown sufficiently, these metals that have been so carefully conserved will no longer be needed. For materials which are not in short supply, as for instance iron and aluminum, present exports can in no way endanger the supply of metal needed for the industrialisation of Canada. It is highly desirable that the country's metal exports should leave in the most highly manufactured form that is commercially feasible, but the pursuit of this objective need not restrict the growth of the mining industry nor of the export of raw materials.

The decision to exploit an ore deposit depends, therefore, upon current costs and prices and the way costs in Northern Canada

compare with those elsewhere. There are a number of additional expenses to be borne by a mining operation located in Northern Canada, arising from the climatic conditions and the remoteness of the area. Thus labour is costly and unsettled because of the unpleasant climate and the isolation. Climate is also responsible for direct costs in terms of additional heating and lighting. Climate also makes the area unsuitable for most activities other than mining thus incurring higher costs for transportation and utility facilities. The foremost problem is that of the availability of transportation facilities[30]. The direct effect of climate is not serious in the provision of adequate road and rail connections, though it does impose seasonal limitations on water transportation. The greatest problem is the shortage of freight to share the fixed costs of the transportation facilities with the mineral producers. This situation is acute in railroad transportation. Northern Canada is one of the few regions of the world where there is a complete absence of any economic product of significance other than minerals[31].

In the section that follows an attempt is made to assess the magnitude of the additional costs incurred by a mining operation located in Northern Canada.

Dubnie estimates that mining costs are likely to be of the order of $3.00 per ton more in the Northern regions than elsewhere in Canada[32]. This differential includes cost of supplies, cost of power and services to employees but does not include the cost of transporting the mineral product to the consuming centre, which is an expense that in a number of cases is dominant. An estimate of the cost of transportation of the product to markets is difficult to

assess. However, in Table IV-9 some costs have been selected to facilitate a comparison of the accessibility of various parts of Northern Canada.

TABLE IV-9 Transportation Costs[33].

Tons per year	Rail	Sea
10,000,000	1¢ per ton mile	.1¢ per ton mile
500,000	3¢ per ton mile	.3¢ per ton mile

Using these rates, the haul from Pine Point to Edmonton costs $6.00 per ton and an Atlantic crossing $3.00 per ton for large annual tonnages while at the lower tonnage charges of $18.00 per ton and $10.00 per ton respectively would be made. These rates are probably close to the minimum attainable by conventional methods of transportation.

Dubnie has found it convenient to divide Northern Canada into areas depending upon how transportation facilities are and might be established. The Eastern Access region comprises the Ungava Peninsula and the area bordering the Hudson's Bay. This region is limited in the west by a north-east extension of the Manitoba-Saskatchewan boundary. The Western Access region is, essentially, the Yukon while the Central Access region is the area in between the Western and the Eastern regions.

During the summer months the Eastern Access region is well situated for water transportation to the Eastern United States and Europe, and in no case need the rail haul be more than 400 miles. The Western region is well situated in relation to the Far Eastern and West Coast markets and once again the maximum rail haul needed to reach an ocean port is 400 miles[34]. However, this is a very mountainous country and direct routes cannot be followed. The Central Access

region is the least accessible of all. An arc of 400 miles radius from Grimshaw or Waterways still excludes a large portion of the area, though if such an arc is centred on Pine Point, the projected rail-head, almost the whole area is included. A further point is that a maximum 400 mile rail haul places mineral products from the Eastern and Westernregions on the coast where they are in easy contact with world markets. An even longer rail haul in the Central Access region places products at Edmonton, which is itself remote and inaccessible to world markets. These areas and distances are illustrated in Figure IV-1.

It will be noticed that we have excluded from this discussion any consideration of transportation routes from the Arctic coast of the Central Access region. To date, it is usually assumed that some development in ocean-going transportation equipment would be needed to establish a regular service to points on this coast[35]. When the improvements are made, it is believed that the North Central Access region can be discussed in exactly parallel terms to the Western Access region.

Ore mined from a deposit in the Canadian North has thus to meet additional costs as compared with those incurred by a similar operation in Southern Canada. Table IV-10 lists these additional expenses for each of the access areas. The "very large operation" described in the table would be an iron ore mine and the "large operation" would be a sizable base metal mine. The tonnages involved would be of the order of those suggested in Table IV-9 though in most cases two or more mines would be expected to make up the total hauled per year.

TABLE IV-10 Additional Expenses of Mining in Northern Canada ($ per ton ore).

	Very Large Operation	Large Operation
Additional Mining Costs	$ 1.00	$ 1.50-$3.00
Transportation		
Max. rail haul, East + West (400m)	$ 4.00	$12.00
Max. rail haul, Central (1,000m)	$10.00	$30.00
Min. rail haul, Central (400m)	$ 4.00	$12.00

The additional costs for mining are somewhat lower than those suggested by Dubnie since the scale of operation he has considered is much smaller than that envisaged here. As explained later, the smaller mining operations are not to be included at this stage of the discussion.

Comparisons between mining costs in various areas have been drawn up on the basis of the grade of ore needed to support a profitable mining operation. If an excessive increase in grade is called for, then it is apparent that the establishment of a mining operation is most unlikely, if not impossible. It is necessary, therefore, to list metal prices to be used to assess the increase in grade required; these figures, contained in Table IV-11, were taken from the Gordon Report[36]. Except for lead, no adjustment was needed. In addition to the market prices, the value of the metal in concentrates and concentrate grades are also listed.

With these data calculations have been made and the increase in grade needed in various locations for each of the six metals has been estimated. These calculations are presented in detail in Appendix VI. It has been assumed that transportation facilities can be provided, if such a service is needed, at the rates outlined in Tables IV-9 and IV-10.

TABLE IV-11 The Value of Metal in Various Forms, 1960 Prices (¢ per lb. of metal).

Metal	Price	Price of Metal in Concentrate or Ore	Concentrate or Ore
Iron, pig	3.4	1.0	51.5% Fe
(steel)	4.0		(ore)
Copper	33.5	27.0	25.0% Cu
Lead	12.0	8.0	70.0% Pb
Zinc	13.5	5.8	60.0% Zn
Nickel	74.0	24.0	15.0% Ni
Aluminum	26.0	1.3	27.0% Al

Taking first the case of an iron ore deposit: if it is located in either the Eastern or Western Access areas it will probably be exploited fairly soon, as are the Schefferville deposits at present. However, once the rail haul becomes more than a few hundred miles, mining operations become less feasible. An important factor in the development of mineral deposits in the Eastern Access area is that ports on Hudson's Bay or on the Ungava Peninsula are almost as close to Europe, by sea, as they are to the North-Eastern United States. Similarly, deposits in the Western Access area are in competition with any on the shores of the Pacific, if they are well located.

Iron ore deposits in the Central Access area appear, for the time being, to be inaccessible except for local markets. A minimum surcharge of $5.00 per ton of ore is needed to bring it to Edmonton or to a port on the Pacific Coast or Hudson's Bay. To compete on a world market this ore would have to be 25% iron higher in grade than ore mined usually; no deposit of such a grade has been found (50 + 25 = 75%) apart from small occurrences of meteoritic iron. Iron ore supplied to Edmonton would not compete on a world market but on world market plus freight to Edmonton basis, in which case Central Access ore might be cheap enough for local use.

(It is interesting to note that extensive iron deposits have not been found in the Cordilleran zones with anything like the frequency that they occur in the Pre-Cambrian geologic structures.)

Reference to Table IV-11 shows that iron is by far the cheapest of the metals considered and, this being so, transportation costs are likely to be of much greater significance than for the other metals. The advantages gained by beneficiation at the mine site are thus very great. Furthermore, due to the very large scale of operation envisaged, the additional mining cost of $1.00 per ton for Northern deposits may be on the high side in such cases. A third point in favour of Canadian deposits is the fact that ore prices are usually quoted on the basis of f.o.b. Lower Lake ports; even the Mesabi ores incur transportation charges of at least $3.00 per ton.

It is evident that some of the deposits of iron ore in the Eastern and Western Access areas are going to be available for world consumption. Let us look briefly at the competition they will have to meet and note which markets are favourably situated. Table IV-1 shows that the United States, Western Europe and Japan are likely to be in need of high grade iron ores or concentrates. Each of these consuming areas could be supplied from deposits in the Eastern or the Western sections of Northern Canada. The principal competition for these exports would come from South American, African and European deposits. In almost all cases these deposits are less than 200 miles from ocean transportation facilities.* The ocean distances between Canadian ports

*A deposit in Mauretania is now being developed which requires the construction of a rail-road over 400 miles long. The grade of the ore is 63% iron[37].

and consuming centres are generally less than those traversed by her competitors but Canada suffers from the disadvantage of a shorter shipping season in some cases.

In summary, it appears that suitably located deposits in the Canadian North are fully competitive with those elsewhere in the world, particularly if the full effect of concentrating the ores before shipment is secured.

The situation for copper is somewhat different from that for iron. Copper is a relatively expensive metal and for the most part it enters world trade in the purified, metallic, form. Transportation is not so important a factor as in the case of iron.

In the Eastern and Western Access areas, ores of 1.70 to 2.00% are the minimum grades that can be exploited when the concentrates are transported for smelting elsewhere (see Table IV-12). An example of a marginal deposit is that at Granduc near Skagway. This deposit contains about 25,000,000 tons of ore running 1.6% copper. Even though this deposit is close to the sea, mountains make access difficult so requiring an additional investment of substantial proportions, and thus mining operations have been postponed[38].

If the deposit is large enough and appropriately located, a substantial savings in transportation costs may be secured by smelting the concentrates close to the mine. A deposit large enough to produce about 25,000 tons of copper per year is usually the smallest size operation that is likely to be commercially attractive, although the location of other smelters, the cost of fuel and other factors are of significance. The minimum grade that can be mined under the most adverse conditions, where smelting is done at the mine site, is still

less than 2.0%.

Copper produced from deposits located in the Northern parts of Canada would have to be marketed on a world basis. Table IV-2 suggests that Western Europe and the Far East are likely to be the best markets for some years to come. Canadian copper will have to compete with the exporters of Peru, Chile, Central Africa and, in time, Mount Isa in Australia. The South American deposits are located close to the sea and are of good grade. The mines of Central Africa are of very good grade, 3 to 5%, but there is quite a substantial freight charge of the order of 2¢ per lb. of outgoing copper plus the cost of an ocean crossing. The key factor in the case of the Central African ores is local political instability.

TABLE IV-12 Minimum Grade Required to Support Operations in Northern Canada.

Metal	Base Ore Grade %	Minimum Grade of Ore, % — Mining $1.50/ton: Trans. nil	Mining $1.50/ton: Trans. $12.00/t.	Mining $3.00/ton: Trans. $12.00/t.	Mining $3.00/ton: Trans. $30.00/t.
Copper conc.	1.25	1.53	1.68	2.00	2.32
Copper metal	1.25	1.53	1.56	1.85	1.91
Lead conc.	3.00	3.94	4.41	5.45	6.65
Lead metal	3.00	3.94	4.26	5.26	6.00
Zinc conc.	5.00	6.29	7.60	9.12	13.30
Zinc metal	5.00	6.29	7.02	8.45	10.00

The mine at Mount Isa, which is being expanded rapidly at present, is about 600 miles from the coast and is thus one of the world's least accessible deposits. However, mineral products are not the only freight, and agricultural and other commodities share the fixed costs of the rail-road system. The railroad is at present being extensively rebuilt at the cost of about $60,000,000 of which the Commonwealth Government is contributing two-thirds[39].

A large deposit of copper of good, though not exceptional grade, could be exploited effectively anywhere within the area of the Canadian North if transportation facilities were available.

The situation for lead and zinc is once again different from that of the two metals discussed already. These two metals are less valuable than copper but more valuable than iron; transportation costs can thus be a very significant item in the exploitation of an ore deposit. On the other hand, very high grade concentrates of both of these metals (60% for zinc and 70% for lead) can be prepared and the advantage of smelting at the mine site is to some degree offset. Table IV-12 shows the ore grades needed to support mining operation in the remoter parts of Canada. The figures suggest that not excessively high grades are needed either in the Eastern and Western or the Central Access regions. Furthermore, in the case of lead and zinc there is a mitigating factor since neither of these metals occurs alone in nature to any extent. The two metals may occur together in deposit, lead with silver or copper with zinc. In this way mining costs per pound of metal are lessened although no reduction in the transportation charges on comparable terms can be expected.

These figures suggest that the deposit at Pine Point may be only marginal at the present prices of lead and zinc.* The grades of ore required, according to Table IV-12, are in all cases less than those of the Australian deposits, which are over 10% of each metal, but are considerably higher than the ore in many places including

*Pine Point ore runs 4% lead and 7.4% zinc while Kimberly is 3.69% Pb and 5.11% zinc according to company reports[40].

the United States[41].

Lead produced by mines operating in Northern Canada would be in competition with those of the main exporters of lead in the world. The important exporters include, besides Canada, Australia, Peru, Mexico, North Africa and the Belgian Congo. The pattern of world trade appears to be governed both by distances and by ownership. Thus Mexican (A.S. and R., A.M.C., Howe Sound) and Peruvian (Cerro de Pasco) lead goes to the United States and Moroccan (Penarroya) to Europe. Australian lead exports, being so large, go to a large number of countries but are concentrated in the United States and the United Kingdom as are the Canadian metal exports. The market for lead from Northern Canada is not obvious, but it seems evident that consumers in the United States, Europe and Japan should all be accessible and that competition from Peru and Australia could be met adequately. Domestic mine production, in the case of the United States, and secondary metal in all the industrialised areas, are likely to represent the most serious competition to mine output from the Canadian North; the competition offered by secondary metal is particularly severe in view of the inelasticity of supply of old scrap.

For zinc a similar situation to that for lead pertains, except that scrap is not a significant factor and that deposits of zinc ore are more widely dispersed and of somewhat higher grade than those of lead. The main consuming areas, in this case, are closer to being self-sufficient in terms of new metal than they are for copper or lead. Thus Japan imports no zinc, North America as a unit can supply its own needs, and Europe provides half of its requirements from its own mines, compared with copper where less than 10% of its

requirements are mined on the continent. The large zinc exporters of the world are Peru, Mexico, Canada, Belgian Congo and Australia. A substantial proportion of these exports of zinc are in the form of concentrates rather than refined metals, there being relatively few zinc smelting and extraction plants in the underdeveloped countries. The refining of zinc is more complex and costly than that of lead (7.7¢/lb for zinc against 4.0¢/lb for lead) and here Canada has an advantage with her advanced technology.*

Zinc producers in the Canadian North will have to compete against the output of mines situated at considerable distance from their markets, except for the case of Mexico supplying the United States. Transportation costs for metallic zinc are significantly lower than those for concentrates, in terms of cents per pound of metal and here an integrated Canadian producer has a further benefit. However, to offset this advantage to some degree, the smelters and refiners in the consuming countries often have surplus capacity, actual or potential, and are able to offer processing charges that are lower than the costs of an integrated operation close to the mine site.

In Appendix VI it has been assumed that, in broad terms, nickel is similar to copper. Certainly the ore mined is often only a little different from that of copper ore in grade and also the value of the metal in concentrate is about the same. The principal differences are that processing of nickel concentrates is considerably

*The ratio of refined metal output to total mine output for a number of countries for 1958 is as follows:

Canada: 59.5%	Australia: 52.0%
Mexico: 25.6%	Belgian Congo: 46.9%
Peru : 22.4%	N. Rhodesia :100.0%

more complex and the grade of concentrate that can be made may be quite low, being always less than 15% nickel. In fact, it is really not possible to make the generalisations about this metal that can be conveniently proposed for copper, lead and zinc. This limitation is imposed because there are no readily available treatment charge schedules for nickel concentrates and because the number of examples of nickel processing operations is very small. The value of the metal makes it possible to operate smaller integrated processing plants than for copper and to transport these relatively low-grade concentrates over considerable distances. On the other hand, an integrated plant close to the mine is likely to have a considerable treatment cost differential with which to work. Thus the integrated plants of the International Nickel Company at Copper Cliff produce about 150,000 tons per year of both nickel and copper, while Sherritt Gordon at Fort Saskatchewan has an output of one-tenth of this level based on ores of about the same grade (about 1.2% Ni). The mine at Rankin Inlet has operated for a few years on an ore containing about 3% nickel and 1% copper. The deposit is quite small and does not justify the installation of smelting and refining facilities: the freight rate on concentrates from the mine on the shores of Hudson's Bay to Fort Saskatchewan, where it is processed, amounts to a total of $22.00 per ton[42].

Due to the relatively high value of the refined metal and to the lack of competition, at present price levels, any of the large consuming areas could be supplied from the Canadian North.

A study of the position for aluminum is not truly a part of

this thesis since to date, and probably for many years to come, the production of this metal in Canada is due entirely to the availability of cheap power and not to sources of ore. It is probable that eventually some non-bauxite ores occurring in the Canadian North will be exploited, but in view of the high elasticity of supply of aluminum ores, it is doubtful that such deposits will be important for a number of years to come.

Work proceeds year by year on methods for exploiting non-bauxite ores and it may be that deposits of these materials close to inaccessible sources of power could be used to create an integrated operation. A development of this kind might be very appropriate if large resources of oil, coal, natural gas were discovered on the Arctic Islands or on the adjacent mainland.

Thus far we have discussed the grade of deposit that can be exploited and the general location of markets for the products from mines in Northern Canada. A further essential point for consideration is the size of the mining operation. Earlier, arbitrary tonnage rates of 10,000,000 tons per year and 500,000 tons per year were set; these figures represented the annual volume of mineral products transported each year and did not necessarily represent the output of one mine, but of several. It is fairly evident that at the 10,000,000 tons per year the transportation cost figures can be readily justified.

At the lower annual tonnage rate, the cost of $.03 per ton-mile may seem on the high side. We are here assuming that the only significant commodity for transportation is the mineral product; supplies brought in do not amount to more than a small proportion of the outgoing freight for a base metal operation. An examination of the recent

railroad construction costs to outlying mining districts suggests an overall capital cost of about $150,000 per mile (see Appendix VII). If such a railroad is depreciated over 30 years, annual charge of $5,000 per mile would have to be met, and this reduces to 1¢ per ton-mile if a total of 500,000 tons is transported per year. At lower annual tonnages carried, the capital charges increase proportionately.

An example of these problems is provided by the railroad extension from Sherridon to Lynn Lake. Here a rate of about 1.67¢ per ton-mile has been established in addition to an annual charge amounting to $2,500 per mile of new track[43]. The latter sum is almost entirely repayable once about 2,000,000 tons have been shipped by the railroad. It should be noted that, of the total haul of about 750 miles, only about one-fifth is over the extension that serves the mine alone.

The validity of the cost and grade calculations are very much dependent upon the tonnages produced and transported due to the importance of fixed costs in these industries. Taking transportation costs first, as the tonnage of freight hauled increases the minimum ore grade differential falls. The tonnage we have considered is, however, considerable referring as it does to mineral products alone, and amounting to more than half the total tonnage of lead, zinc and copper metal produced each year in Canada currently. At lower annual tonnages the freight rates assumed for the calculations are on the low side, and if the volume of concentrates and metal fell to less than 250,000 tons per year, the depreciation charges on a 30 year basis become excessive.

Trucking is a possibility for lower annual tonnages, and costs at close to 5¢ per ton-mile have been attained at annual tonnages

of less than 50,000 tons between Elsa and the rail-head at Whitehorse. In addition to the over the road costs, it is estimated that it costs $40,000 per mile to construct a gravel road for concentrate shipments by truck[44].

The scale of mining will also have an effect on mining costs. This matter has been dealt with arbitrarily in the assignment of graduated increments for the additional costs incurred by mining in the remote areas of the North. Thus $1.00 per ton additional costs was assumed for a large-scale iron ore operation and $1.50 to $3.00 per ton for the smaller scale non-ferrous operation. These figures are partly based on Dubnie's study and partly selected so as to obtain a range of values that allows conclusions to be drawn for a number of examples. No attempt will be made in this study to tie costs and grade to the scale of mining since too many local factors enter into such a relationship. However, grade differential equivalents can be calculated for a series of mine ore grades as has been done in Appendix VI and thus the increase in grade needed for each scale of operation can be calculated where the appropriate data are available.

Where smelting is considered as a possibility, or even a necessity, some rough calculations as to the size of deposit can be made. Thus to support a minimum sized copper smelter of 25,000 tons per year copper, a deposit of 40,000,000 to 50,000,000 tons of 1.25% copper mined at a rate of 6,000 tons per day over 20 years would be needed. The minimum size of lead and zinc smelters is much dependent upon local conditions, as for example fuel and skilled labour. If the same metal production rate for lead and zinc as for copper is assumed, the figures obtained will be quite realistic: a lead ore-

body of 16,000,000 to 20,000,000 tons at 5% lead and zinc ore-body of 8,000,000 to 10,000,000 tons of 5% zinc would thus be the minimum size for integrated smelters in remote areas of the Canadian North.

No effective generalisations can be made about the minimum size of ore deposit needed if concentrates are shipped. A number of smaller producers, if suitably located, and if competent to work with one another could, in most cases, operate almost as effectively as one large producer. Putting forward the suggestion that a number of small producers can be almost equivalent to one large, we are implying that transportation costs are of over-riding importance. This contention will now be examined.

Thus far, in our consideration of the costs that mining in Northern Canada might encounter that are in excess of those faced elsewhere in the country, emphasis has been placed on the product-transportation costs. Reference to Appendix VI shows, however, that for the examples chosen transportation costs were not the largest single item. The composite figure for additional mining costs at $1.00 and $3.00 per ton is, in fact, large when compared with a total of $4.00 to $5.00 per ton for an underground mining operation at 1,000,000 tons per year elsewhere in Canada.

The reason for the emphasis on the product-transportation costs is that unless a relatively large scale operation is undertaken, capital charges become excessive. This situation is illustrated by Table IV-13.

It appears that the product-transportation charges could easily become the critical factor unless operations of the scale we have considered here are contemplated. It will be remembered that a

25,000 tons per year copper smelter was suggested as the smallest commercial unit, and that only the extremely large base metal operations produce more than 100,000 tons per year.

TABLE IV-13 Railroad Capital Charges.

Tons per Year	Capital Charges at 5% over 30 years for 400 miles haul one-way $/ton
10,000,000	.39
1,000,000	3.90
500,000	7.80
250,000	15.60
100,000	39.00
25,000	156.00

The additional costs items that have been collected together under the one heading, bear some further examination. This composite figure includes the additional cost of labour, power, supplies, capital, inventory of supplies, inventory of output and a number of others. As indicated earlier, most of these additional costs are attributable to the climate and to the isolation of Northern Canada.

Labour costs, it is found, are only a little higher than elsewhere in the country although the cost of services to employees, such as housing, are quite substantial[45]. The additional cost of power is only partly due to the higher cost of fuel supplies. Power is also expensive because isolated communities only require the small generating units which are intrinsically more expensive per kilowatt-hour than the large units. The additional cost of supplies is almost entirely a matter of transportation charges while plant capital costs are higher for the same reason and because of higher overall labour costs. Higher inventory charges can also be ascribed to inadequacies in the transportation system. Tabulated below is a suggested break-down

of the $3.00 per ton additional mining charge we have applied.

TABLE IV-14 Additional Mining Costs.

Services to labour	$1.00/ton additional
Supplies to operation	$ .75/ton "
Power	$ .50/ton "
Heating	$ .25/ton "
Inventory of supplies	$ .50/ton "
	$3.00/ton

The figures suggested by Dubnie, and upon which Table IV-14 is based, refer to the relatively small operations at present established in the Canadian North. With the improved transportation facilities, that in most cases would be essential for a larger plant, it is anticipated that the cost of supplies to the operation and the cost of the inventory of supplies would fall. A very large operation would reduce the premium on power and supply inventory to a negligible level while the cost of services to labour and supplies to the operation would also fall substantially. The latter might well include only handling charges, ultimately, the out-going freight bearing all the capital charges.

It thus appears that the range of from $3.00 per ton to $1.00 per ton additional cost of mining, exclusive of the expense of shipping the mineral product to the consuming centre, is adequate, without including unreasonable figures.

The competitive position of the mining industry in Northern Canada appears to be weakened in that there is a complete lack of external economies. Distances call for an extensive transportation system and for independent supplies of power and energy, but the weather is so inclement that no economic activity of any significance other than mining can survive.

We have excluded from our discussion the precious and rare metals since deposits of the former are exploited today under Northern conditions and the latter are not commercially proven elsewhere in the world. We have also avoided discussion of hindrances to trade, such as tariffs, quotas, embargoes and so on since they apply to mineral products mined anywhere in Canada and do not present difficulties that relate uniquely to the Canadian North.

Let us now recapitulate briefly the conclusions that can be drawn from the discussions in this chapter and thus of the thesis as a whole.

Overall, there does not seem to be a likelihood of a chronic shortage of any of these metals. This situation is due to the abundance of ore, in some cases, and to the possibility of substitution in others.

The organisation and structure of each of the industries participating in the production of the six metals has also been examined. A wide range of types of industry structure is encountered, none of which needs ban a new entrant, though the market uncertainties presented by some may discourage a marginal producer.

There appears to be no advantage gained in delaying the exploitation of a deposit of any of the six base metals that can be economically worked. Of the six mineral products, iron and aluminum are in very elastic supply and a mine operator would have to wait too long a period for any substantial price rise.* Copper, lead and zinc should similarly be exploited promptly because elasticity of demand is likely to dissipate any potential gains made through temporary shortages in

*This assumes that real prices are being considered and that the mine operator could, as an alternative, invest his capital and get interest at commercial rates.

supply. The position of nickel is more complex in that the metal is used to a considerable extent in conjunction with other metals and because its price is closely administered.

The grade of deposits that can be exploited in Northern Canada depends upon a number of factors, but in no case is an ore of unlikely richness required to support a profitable mining operation. In this study, however, the Arctic Islands were not specifically included, and here extremely high grade deposits might be needed.

Furthermore, large deposits are needed to sustain a transportation system. Many small deposits could be worked together, so producing a substantial total though large deposits would have many advantages.

Northern Canada, as a whole, presents some interesting problems due to the apparent lack of potential benefits to the mining industry through external economies.

Mineral deposits located in Northern Canada can be competitive with those anywhere in the world and can capture their share of the market, provided and only provided, transportation facilities are available on the same basis as elsewhere in the country. In essence then, it is a problem of transportation facilities. The future of the North depends upon whether these transportation facilities are to be provided now before their economic justification, or whether mineral resources of significant magnitude must first be proven.

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Appendix I

Deployment of Labour Force (% distribution).

Occupation	Canada 1951	Mexico 1950	W. Germany 1950 Total	W. Germany 1950 Men	United Kingdom 1951
Agriculture	19	55	23	16	5
Mining + Quarrying	2	1	3	4	4
Manufacturing	26	13	31	35	37
Construction	7	3	8	12	8
Gas + Electricity	1	--	1	1	2
Commerce	16	9	10	9	14
Trans. + Comm.	8	3	5	8	7
Services	20	11	17	11	23
Other	1	5	2	2	--
Working populations millions	5.3	7.8	22.1	14.1	20.3

Source: United Nations, Statistical Handbook, 1957, New York, 1958.

Appendix II

Calculation of the Metal Content from Machinery Value.

In many cases import-export statistics are presented only in terms of the value of the transaction. Such data are not of great assistance when the quantity of metal involved is the information required.

Export figures presented by the United Nations do, however, give some indication of a value/metal content factor[1]. Some selected figures are shown below.

British Exports	\$ per ton			
	'54	'55	'56	'57
Iron and Steel - Semi-fabricated	160	157	158	185
Power Plants, steam	1,463	1,574	1,770	2,130
Machinery, not otherwise specified	--	1,282	1,378	1,484
Generating equipment - electrical	1,520	1,510	1,555	1,624
Construction and Mining Equipment	869	911	950	1,026
Railway Vehicles	574	565	590	438

German Exports	\$ per ton			
	'54	'55	'56	'57
Machinery, not otherwise specified	1,201	1,224	1,293	1,305
Metal-Working Machinery	1,360	1,348	1,304	1,419
Electrical Machinery	1,630	1,913	2,007	2,007
Road Vehicles	1,170	1,178	1,200	1,239
Rail Vehicles	650	528	534	578

For preliminary calculations it has been assumed that machinery is worth about \$1,500 per ton. A second assumption that has been made is that machinery is made of metals in about the proportions used by the economy as a whole. Thus for the United States in recent years the proportions are as follows:

Steel, ingot output	100
Steel in semi-manufactured form	73
Steel as machinery	82
Iron Ore (iron content)	67

Copper - new	1.2
Zinc - new	.85
Lead - new	.63
Nickel - new	.11
Aluminum - new	1.55

Exports of semi-manufactured steel and machinery to the underdeveloped countries has been calculated. In 1957 the machinery exports were estimated as being a total of $9,304 billion[2]. This total contained 6,000,000 of steel, using the estimated value of machinery at $1,500 per ton. In addition an estimated 10,000,000 of steel as structurals and other semi-manufactured products was exported[3].

The quantities of metals exported to the underdeveloped countries in machinery or as semi-manufactured goods is now calculated:

Ingot steel for machinery exports	9,000,000
Ingot steel for semi-manufactures	13,300,000
Total ingot steel	22,300,000
Iron as iron ore	15,600,000
Copper	280,000
Zinc	198,000
Lead	147,000
Nickel	25,600
Aluminum	361,000

It will be noted that in no case are these figures added into the total consumption for each metal since they are already included once.

A second approach follows an estimate of the total investment that might be made by and on behalf of underdeveloped countries.

It has been estimated that about 1,000,000,000 people share a total Gross National Product of $125,000,000,000[4]. This total excludes the developed countries and the Soviet bloc nations. We have then assumed that an investment of 12.5% per year of this

Gross National Product is made by these peoples, so bringing about a growth of 3.5% per year in their total Gross National Product[5]. The annual investment at the end of 25 years by these peoples will then be:

$$\frac{125,000,000}{2} \times 2.5 \times \frac{12.5}{100} = \$39 \text{ billion/year}$$

Assuming that half of this investment outlay is used for the purchase of machinery and equipment, the quantity of steel consumed in equipment is thus:

$$\frac{39,000,000,000}{1,500} = 13,000,000 \text{ tons/year}$$

The concurrent consumption of the other metals is then estimated as follows:

Ingot steel	19,500,000
Steel in machinery and equipment	13,000,000
Iron content of pig iron	13,000,000
Copper	234,000
Zinc	166,000
Nickel	21,000
Aluminum	292,000

Once again, to avoid double counting these quantities have not been included in the total world consumption of metals in 1980.

References

1. United Nations, International Trade Statistics, 1957, Vol. I, New York, 1958.

2. Ibid.

3. Ibid.

4. United Nations, Statistical Yearbook, 1958, New York, 1959.

5. Lewis, W.A., The Theory of Economic Growth, Allen and Unwin, London, 1955, p. 201 et seq.

Appendix III

Tonnages of ore that might be mined from a "typical" porphyry ore body.

Rearranging Lasky's equation

$$\log \text{tonnage} = \frac{12.9 - G}{1.4}$$

Grade, G % Cu	Tons of Ore	Tons of Copper	Marginal Grade % Cu
1.4	162,000,000	22,650,000	
			.685
1.2	224,000,000	26,900,000	
			.510
1.0	316,000,000	31,600,000	
			.315
.8	446,000,000	35,700,000	
			.077
.6	616,000,000	37,000,000	
.4	870,000,000	35,800,000	
.2			
nil	1,620,000,000!		

The equation must therefore only be applied over a certain range of ore grades or else one encounters an apparent shrinkage of the metal content of the deposit as it extended to lower grade zones!

Appendix IV

S.G. Lasky's Factors.

1) Lead

Cumulative output $y = \dfrac{33.5 \times 10^6}{1+31.5\, e^{-.65x}}$

Annual output $\dfrac{dy}{dx} = \dfrac{69 \times 10^6\, e^{-.65x}}{(1 + 31.5\, e^{-.65x})^2}$

2) Zinc

Cumulative output $\int y = 6.7 \times 10^5 \displaystyle\int_{1858}^{x} \frac{dx}{1 + 245\, e^{-.124x}}$

Annual output $y = \dfrac{6.7 \times 10^5}{1 + 245\, e^{-.124x}}$

3) Copper

Cumulative output $y = 7.3 \times 10^5 \displaystyle\int_{1845}^{x} \frac{dx}{1 + 51.1\, e^{-.122x}}$

Annual output $\dfrac{dy}{dx} = \dfrac{7.3 \times 10^5}{1 + 51.1\, e^{-.122x}}$

4) Aluminum

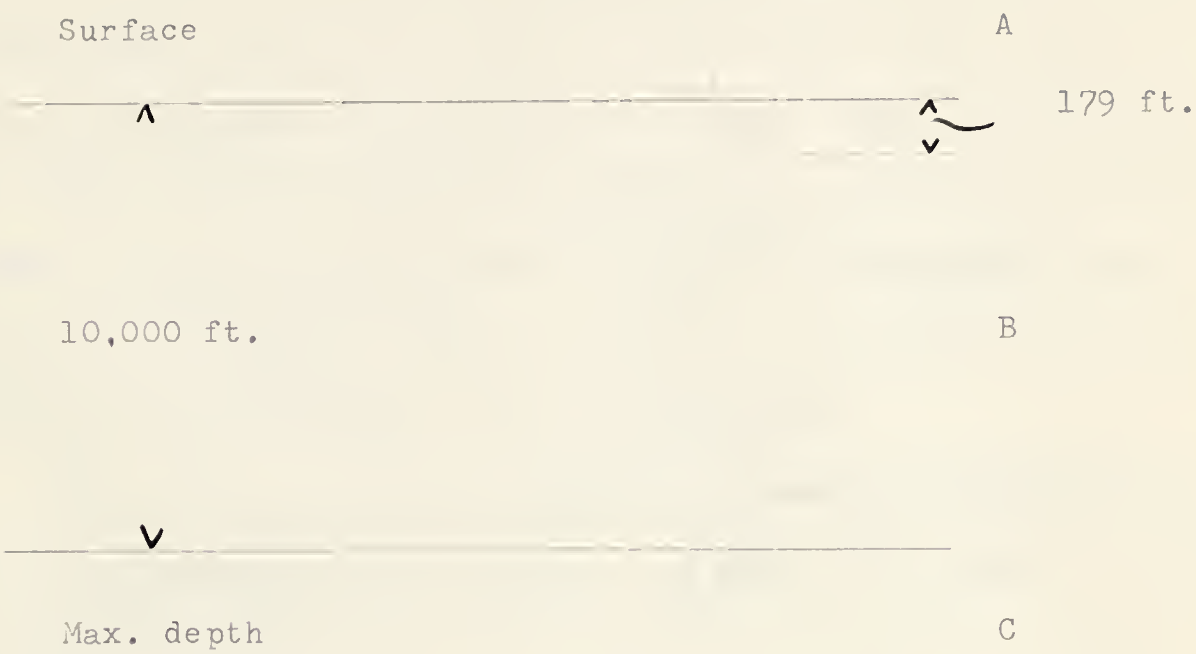
Cumulative output $y = 1.5 \times 10^6 \displaystyle\int_{1886}^{x} \frac{dx}{1 + 255\, e^{-.121x}}$

Annual output $y = \dfrac{1.5 \times 10^6}{1 + 255\, e^{-.121x}}$

Note: Care has been taken to write these functions exactly as presented in the article.

Appendix V

Ratio of Concealed to Surface Ore.



Assume:

(a) Ore body of 100,000,000 tons
(b) Specific gravity of the ore is 4.0
(c) Ore body is a compact sperical form.

Diameter of this idealised ore body is calculated as follows:

Volume of 100,000,000 tons of ore is

$$\frac{100,000,000 \times 2,000}{4 \times 62.5} = 800,000,000 \text{ cubic ft.}$$

Volume of sphere $= \frac{4}{3}\pi r^3$

$$r = \sqrt[3]{\frac{3 \cdot 800,000,000}{4}}$$

$$= 100\sqrt[3]{\underline{3 \cdot 200}} = 579 \text{ feet}$$

If the original surface at time of emplacement of the ore body had been removed so that only a portion of the ore body in position A was left, A represents one extreme position of the ore body for if it were placed any higher with respect to the present surface, only a relatively small ore body would remain. From position A the ore body can be placed (400 + 579) feet lower and still give some surface showing. Position B represents a completely concealed ore body, while C is an ore body only just in the minable range in relation to the maximum economic depth. The selection of the exact positions of the extremes A and C is arbitrary.

The ratio of possible positions to positions under which the ore body presents a surface showing under these highly idealised conditions is thus:

$$\frac{10{,}000 + 2\,(579 - 179)}{400 + 579}$$

$$= 11.0$$

It should be noted that in none of the conditions under which a surface showing is obtained, will the ore body actually be the full 100,000,000 tons since greater or lesser proportions will have been removed by erosion. However, topographical irregularities are almost always present so that a surface showing <u>may</u> be obtained without excessive ore wastage.

Appendix VI

Calculation of Grade Differentials Needed to Support Mining Operations in Northern Canada.

Throughout the discussion of the topic, differentials at several different levels have been considered. These differentials have been calculated as follows:

(a) Mining Cost Differential:

	Very Large	Large
Most favourable	$1.00	$1.50/ton mined
Least favourable	$1.00	$3.00/ton mined

(b) Rail Transportation

	Iron Ore (per ton ore)		Non-Ferrous Metals (per ton conc. or metal)	
	E+W	Central	E+W	Central
Most favourable	nil	$ 4.00	nil	$12.00
Least favourable	$4.00	$10.00	$12.00	$30.00

The cost of transporting the refined metal is assumed to be at the same rates as that prevailing for the concentrate.

(c) Value of Metals

The value of the metals delivered at the smelter are those used in the study by John Davis, "Mining and Mineral Processing in Canada" for the Royal Commission on Canada's Economic Prospects. These figures are listed on page 308. Of the six considered here only that for lead shows a significant difference between May 1957 figures and current prices. The value of metal in concentrate for lead has been adjusted from the earlier 10.8¢/lb to 8.0¢/lb.

(d) Profit on Smelting

It has been assumed that the smelting charges are equal to the cost of smelting. Some profit is usually made, needless to say, but in a remote location cost may be higher than usual.

(i) Differentials for Iron

Ore		per ton	grade differential
	Minimum	$ 1.00	1.00/.01 = 100 lbs ≡ 5.0%
	Minimum Central	$ 5.00	5.00/.01 = 500 lbs ≡ 25.0%
	Maximum E + W	$ 7.00	7.00/.01 = 700 lbs ≡ 35.0%
	Maximum Central	$13.00	

Pig Iron

The possibility of smelting ore to pig iron close to the ore site was not considered in detail. This omission is due to the fact that the weight of coal plus flux plus pig iron comes to considerably more than the weight of iron ore needed to produce one ton of pig iron. A fortuitous coincidence of ore, flux and fuel deposits cannot be entirely ignored, but consideration of such a situation is outside the scope of this study.

(ii) Differentials for Copper

Ore grade - 1.25%
Concentrate grade - 25.0% : i.e. 5% concentrate on ore
Value of copper at smelter ignoring transportation costs
$= 33.5 - 6.5 = 27¢.$

Shipping Concentrate:

A Mining costs at $1.50/ton

Grade diff. equiv. $\frac{1.50}{.27} = 5.6$ lbs $\equiv .28\%$

B Transportation at $12.00 per ton conc. + $48.00/ton Cu

Cost per ton ore: $\frac{5}{100} \times 12.00 = \$.60$

Mining plus Trans. $= 1.50 + .60$

Grade diff. equiv. $= \frac{2.10}{.27 - .024} = 8.5$ lbs $\equiv .43\%$

C Mining costs at $3.00/ton

Mining plus Trans. $= 3.00 + .60$

Grade diff. equiv. $= \frac{3.60}{.246} = 14.6$ lbs $\equiv .75\%$

D Transportation at $30.00 per ton conc. + $120/ton Cu

Cost per ton ore $= \frac{5}{100} \times 30.00 = \$1.50$

Mining plus Trans. $= 3.00 + 1.50$

Grade diff. equiv. $= \frac{4.50}{.27 - .06} = 21.4$ lbs $\equiv 1.07\%$

Shipping Metal:

A Mining costs at $1.50/ton

Grade diff. equiv. $\equiv .28\%$

B Transportation at $\$12.00$ per ton metal

Cost per ton ore $= \frac{1.25}{100} \times 12.00 = \$.15$

Mining plus Trans. $= 1.50 + .15$

Grade diff. equiv. $= \frac{1.65}{.27 - .006} = 6.25$ lbs $\equiv .31\%$

C Mining costs at $\$3.00$ per ton

Mining plus Trans. $= 3.00 + .15$

Grade diff. equiv. $= \frac{3.15}{.264} = 12.0$ lbs $\equiv .6\%$

D Transportation at $\$30.00$/ton metal

Cost per ton ore $= \frac{1.25}{100} \times 30.00 = \$.375$

Mining plus Trans. $= 3.00 + .375$

Grade diff. equiv. $= \frac{3.375}{.27 - .015} = 13.2$ lbs $\equiv .66\%$

(iii) Differentials for Lead

Ore grade - 3.0% (see Minerals Yearbook 1958, p. 639)
Concentrate grade - 70.0% : i.e. 4.3% concentrate on ore
Value of lead to smelter without transportation costs
= $\$.08$/lb

Shipping Concentrate:

A Mining costs at $\$1.50$ per ton

Grade diff. equiv. $\frac{1.50}{.08} = 18.8$ lbs $\equiv .94\%$

B Transportation at $\$12.00$/ton conc. + $\$17.20$/ton metal

Cost per ton ore $= \frac{4.3}{100} \times 12.00 = \$.51$

Mining plus Trans. $= 1.50 + .51$

Grade diff. equiv. $= \frac{2.01}{.08 - .0086} = 28.2$ lbs $\equiv 1.41\%$

C Mining costs at $\$3.00$ per ton

Mining plus Trans. $= 3.00 + .51$

Grade diff. equiv. $= \frac{3.51}{.0714} = 49.0$ lbs $\equiv 2.45\%$

D Transportation at $30.00 per ton conc. + $42.80/ton Pb

Cost per ton ore = $\frac{4.3}{100}$ x 30.00 = $1.28/ton

Mining plus Trans. = 3.00 + 1.28

Grade diff. equiv. = $\frac{4.28}{.08 - .0214}$ = 73 lbs ≡ 3.65%

Shipping Metal:

A Mining costs at $1.50 per ton

Grade diff. equiv. ≡ .94%

B Transportation at $12.00/ton metal

Cost per ton ore = $\frac{3}{100}$ x 12.00 = $.36/ton ore

Mining plus Trans. = 1.50 + .36

Grade diff. equiv. = $\frac{1.86}{.08 - .006}$ ≡ 25.2 lbs ≡ 1.26%

C Mining costs at $3.00 per ton

Mining plus Trans. = 3.00 + .36

Grade diff. equiv. = $\frac{3.36}{.074}$ = 45.2 lbs ≡ 2.26%

D Transportation at $30.00 per ton metal

Cost per ton ore = $\frac{3}{100}$ x 30.00 = $.90/ton ore

Mining plus Trans. = 3.00 + .90

Grade diff. equiv. = $\frac{3.90}{.08 - .015}$ = 60 lbs ≡ 3.0%

(iv) Differentials for Zinc

Ore grade - 5.00% (see Minerals Yearbook 1958, p. 639)
Concentrate grade - 60.0% : i.e. 8.33% concentrate on ore
Value of zinc to smelter without transportation costs
= 5.8¢/lb

Shipping Concentrate:

A Mining costs at $1.50 per ton

Grade diff. equiv. = $\frac{1.50}{.058}$ = 25.8 lbs ≡ 1.29%

B Transportation at $12.00 per ton conc. + $20.00/ton Zn

Cost per ton ore = $\frac{5}{100}$ x 20.00 = $1.00/ton ore

Mining plus Trans. = 1.50 + 1.00

Grade diff. equiv. = $\frac{2.50}{.058 - .01}$ = 52 lbs ≡ 2.6%

C Mining at $3.00 per ton

Grade diff. equiv. = $\frac{3.00 + 1.00}{.048}$ = 83.3 lbs ≡ 4.12%

D Transportation at $30.00/ton conc. + $50.00/ton Zn

Cost per ton ore = $\frac{8.33}{100}$ x 30.00 = $2.50/ton ore

Mining plus Trans. = 3.00 + 2.50

Grade diff. equiv. = $\frac{5.50}{.058 - .025}$ = 167 lbs ≡ 8.3%

Shipping Metal:

A Mining costs at $1.50/ton ore

Grade diff. equiv. ≡ 1.29%

B Transportation at $12.00/ton Zinc

Cost per ton ore = $\frac{5}{100}$ x 12.00 = $.60/ton ore

Mining plus Trans. = 1.50 + .60

Grade diff. equiv. = $\frac{2.10}{.058 - .006}$ = 40.4 lbs ≡ 2.02%

C Mining at $3.00/ton ore

Mining plus Trans. = 3.00 + .60

Grade diff. equiv. = $\frac{3.60}{.052}$ = 69.2 lbs ≡ 3.46%

D Transportation at $30.00 per ton metal

Cost per ton ore = $\frac{5}{100}$ x 30.00 = $1.50/ton ore

Mining plus Trans. = 3.00 + 1.50

Grade diff. equiv. = $\frac{4.50}{.058 - .015}$ = 100 lbs ≡ 5.0%

(v) Differential for Nickel

Ore grade - 1.5%
Concentrate grade - 15.% : 10% of ore is concentrate
Value of nickel at smelter without transportation costs
= $.24

Assume that costs are very similar to those for copper.

(vi) Differentials for Aluminum

This is essentially a problem of energy supply and is thus not a part of this study.

Appendix VII

Railroad Construction Costs to Remote Mining Areas.

Moak Lake spur		
	$ 5,400,000 for 30 miles	$180,000/mile
Beattyville to Chibougamau		
	$18,000,000 for 161 miles	$112,000/mile
St-Félicien to Chibougamau		
	$35,000,000 for 294 miles	$119,000/mile
Heathe-Steele spur		
	$ 3,000,000 for 23 miles	$130,000/mile
Terrace to Kitimat		
	$11,500,000 for 46 miles	$250,000/mile
Pine Point (either route)		
	$60,000,000 for 430	$140,000/mile
Chisel and Optic Lake connections		
	$ 8,840,000 for 52 miles	$170,000/mile
Sherridan to Lynn Lake		
	$20,000,000 for 144 miles	$139,000/mile

For construction in the Canadian North an average figure of $150,000/mile is thus suggested.

It is interesting to note that the Alaska International Rail and Highway Commission on Railway, Construction, Operation and Maintenance suggests a capital cost of $250,000 per mile with annual operating and maintenance costs of $14,285 per mile for a 1,400 mile line. In addition Gritzuk suggests that for a railroad to replace tracks between Dawson and Whitehorse an annual volume of 1,000,000 tons of freight would be needed.


INDEX TO PRINCIPAL PRODUCTIVE MINES
DECEMBER 1956
(WITH NAMES OF OPERATING COMPANIES)
NEWFOUNDLAND
NOVA SCOTIA
NEW BRUNSWICK
QUEBEC
ONTARIO
MANITOBA
SASKATCHEWAN
ALBERTA
BRITISH COLUMBIA
YUKON TERRITORY
NORTHWEST TERRITORIES
NOTES
ARCTIC OCEAN
BEAUFORT SEA
PACIFIC OCEAN
GULF OF ALASKA
ALASKA
GREENLAND
BAFFIN BAY
DAVIS STRAIT
HUDSON BAY
JAMES BAY
HUDSON STRAIT
UNGAVA BAY
FOXE BASIN
GULF OF ST LAWRENCE
ATLANTIC OCEAN
UNITED STATES
WESTERN ACCESS AREA
CENTRAL ACCESS AREA
EASTERN ACCESS AREA
SMELTERS OR REFINERIES
IRON BLAST FURNACES
FERRO-ALLOY PLANTS
NON-FERROUS METAL SMELTERS AND REFINERIES
GOLD
IRON BLAST FURNACES AND FERRO-ALLOY PLANTS
NICKEL, COPPER, LEAD, ZINC, SILVER, COBALT
ASBESTOS, SALT, GYPSUM, FLUORSPAR, SODIUM SULPHATE
IRON, TITANIUM
IMPORTANT POTENTIAL PRODUCING AREAS
LEGEND
Intrusive and undivided rocks of the Canadian Shield
Sedimentary and volcanic rocks of the Canadian Shield
Interior Plains, St. Lawrence Lowlands, Hudson Bay Lowland, and Arctic Lowlands and Plateaux
Innuitian Region
Appalachian Region
Cordilleran Region
Intrusive rocks within the Cordilleran Region
Metal mines
Mining area
PORCUPINE
Industrial mineral mines and quarries
Coal mines
Oil field
Gas field
Oil and Gas field
Oil pipe line
Gas pipe line
Gas pipe line (under construction, proposed)
VALUE OF MINERAL PRODUCTION OF CANADA, 1956
(Preliminary Estimates)
METALLICS
DOLLARS
COPPER 291,469,615
NICKEL 223,343,992
IRON ORE 156,327,885
GOLD 150,808,010
ZINC 125,476,218
LEAD 57,906,514
URANIUM 39,577,000
SILVER 25,831,612
PLATINUM 15,585,000
FUELS
CRUDE PETROLEUM 401,840,650
COAL 95,466,866
NATURAL GAS 17,542,555
INDUSTRIAL MINERALS
ASBESTOS 109,665,924
SALT 13,916,532
GYPSUM 8,300,585
SULPHUR 7,440,410
FLUORSPAR 3,835,565
PEAT MOSS 3,708,191
SODIUM SULPHATE 2,854,223
VALUE OF MINERAL PRODUCTION OF CANADA, 1939 TO 1956
YEAR
DOLLARS PER CAPITA
DOLLARS TOTAL
1939 42.12 474,602,059
1943 44.87 530,053,966
1947 51.38 644,869,975
1948 63.97 870,248,865
1949 67.01 901,110,026
1950 76.24 1,045,450,073
1951 88.91 1,245,483,595
1952 89.07 1,285,342,353
VALUE OF MINERAL PRODUCTION OF CANADA BY PROVINCES, 1956
Newfoundland
Nova Scotia
New Brunswick
Quebec
Ontario
Manitoba
Saskatchewan
Alberta
British Columbia
N.W. Territories
Yukon Territory
CANADA
Cartography by the Geological Cartography Unit, 1957
DEPARTMENT OF MINES AND TECHNICAL SURVEYS
MINES BRANCH AND GEOLOGICAL SURVEY OF CANADA
MAP 900A
CANADA
PRINCIPAL MINERAL AREAS
SCALE 1 INCH TO 120 MILES
MILES 100 0 100 200 300 400 MILES
Printed by the Surveys and Mapping Branch
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DECEMBER 1956
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1 Stony Creek Oil, Gas
ONTARIO
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NORTHWEST TERRITORIES
Norman Wells

B29789